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INFRASTRUCTURE SYSTEMS

AND THE

COST OF OWNERSHIP

BY

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RANDALL C. ORTGIESEN

AUGUST 1991



**CONSTRUCTION  
ENGINEERING &  
MANAGEMENT**  
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INFRASTRUCTURE SYSTEMS  
AND THE  
COST OF OWNERSHIP

A SPECIAL RESEARCH STUDY  
PRESENTED TO

THE FACULTY OF THE CONSTRUCTION ENGINEERING  
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by

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## ABSTRACT

Infrastructure ownership involves much more than the initial cost of acquisition, and one who recognizes this must have an interest in controlling the ownership costs to be incurred over the service life of a particular infrastructure system. This study first introduces infrastructure economics and the various categories of ownership costs in order to lay a foundation for the application of life-cycle costing in infrastructure management. Investigation and analysis of three in service infrastructure systems discusses a few of the many decisions made during design and construction and their impacts on the total cost of ownership. The study concludes with a discussion on controlling the cost of ownership and recommendations for further related work.

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## CHAPTER I. DESCRIPTION OF THE PROBLEM

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### 1.1 INTRODUCTION AND BACKGROUND

Society is faced today with the issue of limited economic and natural resources which makes it increasingly more important for design and construction professionals to implement and follow a methodology that allows for the selection of infrastructure systems sensitive to those limited resources. The methodology must facilitate improved operational performance and result in a lower cost of ownership. With this in mind, infrastructure systems must be planned, designed, constructed, and operated with an emphasis on the economic consequences of each and every decision.

All those involved in any phase of infrastructure management should feel compelled and professionally obligated to strive for and obtain efficient methods to reduce all costs expected to be incurred over the life of a particular system. Engineers and architects need to consider all feasible design alternatives with their varying economies of ownership and the tradeoffs associated therewith. Owners in conjunction with suppliers and builders need to consider the quality and efficiencies of selected materials, equipment, and construction methods. And finally, owners, operators, and custodians must establish cost effective policies for maintenance, repair, and replacement of those selected systems.

Consider the Nation's public assets and imagine the magnitude of the potential for increased ownership costs for these

infrastructure systems if a less than sufficient design is chosen which could result in significant increases to the costs of operation, maintenance, and repair.

"Department of Defense buildings alone are estimated to be worth \$500 Billion. Replacement of the Nation's 88,021 public school buildings may exceed \$422 Billion. It would cost more than \$300 Billion to replace the physical structure of America's institutions of higher learning (public and private). State and local government building replacement value is estimated to be \$400 Billion. Additionally, water supply, waste disposal, transportation, and other physical infrastructure systems, an investment worth many billions of dollars, are beyond the scope of this report but play a similar critical national role"  
(Building Research Board 1990)

These infrastructure systems are public assets that have been acquired and operated through use of taxpayer dollars. Those responsible for infrastructure related decisions are stewards of taxpayer dollars and ultimately responsible for the efficient and economical use of those systems. Therefore, in this era of constantly increasing prices and diminishing natural resources, in combination with increased public scrutiny of infrastructure related budgets, it becomes ever more crucial to insure every dollar invested purchases the best infrastructure system to achieve the required results.

## 1.2 PROBLEM AND SCOPE

The problem with which all those associated with any phase of infrastructure management are faced, is first to become educated in the economics of infrastructure, and second to insure decisions are made such that during the life of infrastructure systems the required results are achieved at the lowest cost of ownership.

"It is unfortunate but inevitable that the construction of new facilities attracts far greater attention than the maintenance and repair of existing ones. While facilities are designed to provide service over long periods of time, the substantial costs of construction are addressed all at once in public debate resulting in management decisions based almost entirely on acquisition costs. In contrast, the yearly cost of maintenance and repair seem small, although over the course of a facility's life they generally total much more than the initial cost of construction".  
(Building Research Board 1990)

Many times public and private organizations are restricted by maximum limits for construction expenditures. If costs can't be kept within budget, the project may be canceled. More times than not, construction costs are reduced and the project is squeezed into the budget for execution only to become a future burden from the system generating higher maintenance and repair costs with less than adequate operational results. The construction costs are usually kept within budget by selecting materials and equipment with lower initial costs and a corresponding shorter service life. Ideally, construction should be planned and funded at the level that meets all the user's requirements for the lowest cost of

ownership over the predetermined life of the selected infrastructure system. Often however, officials making the infrastructure decisions, or their constituents, are not fully aware of the consequences of "building cheaply" which results in the requirement to "expensively maintain" and thereby increases the cost of ownership.

People, especially the leadership sector, do not fully understand the facts. Those making the decisions in combination with others that shape public opinion such as the media and other community leaders are not yet fully aware of the implications of the failure to spend the required money to construct and maintain infrastructure systems that achieve the required results at the lowest cost of ownership. Even some members of the United States Congress do not fully understand the total cost of infrastructure ownership since they regard life-cycle costing as a method by which management costs are increased.

"The conferees understand that the U.S. Army Corps of Engineers may implement a life-cycle management program for the military construction execution process...some concern exists that this may increase management costs...the conferees expect that implementation will be to the field level for only selected projects" (Conference of the Senate and House Appropriations Committees on the Military Construction Budget 1990)

### 1.3 RESEARCH OBJECTIVES

The primary objective of this research is to provide a tool through which the economics of construction can be better understood as it relates to the costs of ownership incurred over the life of a particular infrastructure system.

Using a basic understanding of infrastructure economics and data collected for specific infrastructure systems, historical construction, maintenance, and repair records will be analyzed and interpreted to identify specific items with regard to type and quality of materials and the effects on the cost of ownership. This research will attempt to show for a particular infrastructure system, that maintenance and repair costs are related to and affected by decisions made during design and construction with respect to the type and quality of materials. Through discussion of historical construction and maintenance items for specific infrastructure systems, an important aspect of infrastructure economics will be established.

#### 1.4 STUDY METHODOLOGY

In order to successfully achieve the objective of this study, a foundation of basic understanding must first be developed. Under the assumption not all those associated with infrastructure management have been introduced to the basic principles required to appreciate the total cost of infrastructure ownership, the report format and study methodology first touches on a few essential areas. These key areas will assist in development of an understanding for increased awareness in infrastructure life-cycle costs as they relate to decisions made during design and acquisition on the total cost of ownership.

The previous sections of Chapter I described the problem and provided the objective for this study. Chapter II will discuss infrastructure economics and the various categories of costs for ownership of infrastructure systems. Chapter III introduces life-cycle costing as the methodology by which the best infrastructure system may be selected to achieve the required results at the least cost of ownership, and a present value cost model for life-cycle costing will be introduced. Chapter IV will discuss various methods of forecasting future maintenance and repair outlays for use in life-cycle costing, and also address the issue of risk management in the area of decision making. Chapter V presents the analysis and discussion of the data collected through contact with public and private agencies. Additionally, an assessment will be made as to what extent decisions made during design and acquisition

had a positive or negative impact on the total cost of ownership. Chapter VI will provide the obstacles to and recommendations for controlling the cost of infrastructure ownership, and Chapter VII concludes the study with a discussion on fulfillment of the objective and recommendations for further related work. Figure 1.1 shows a schematic of the study methodology.

## STUDY METHODOLOGY FLOWCHART

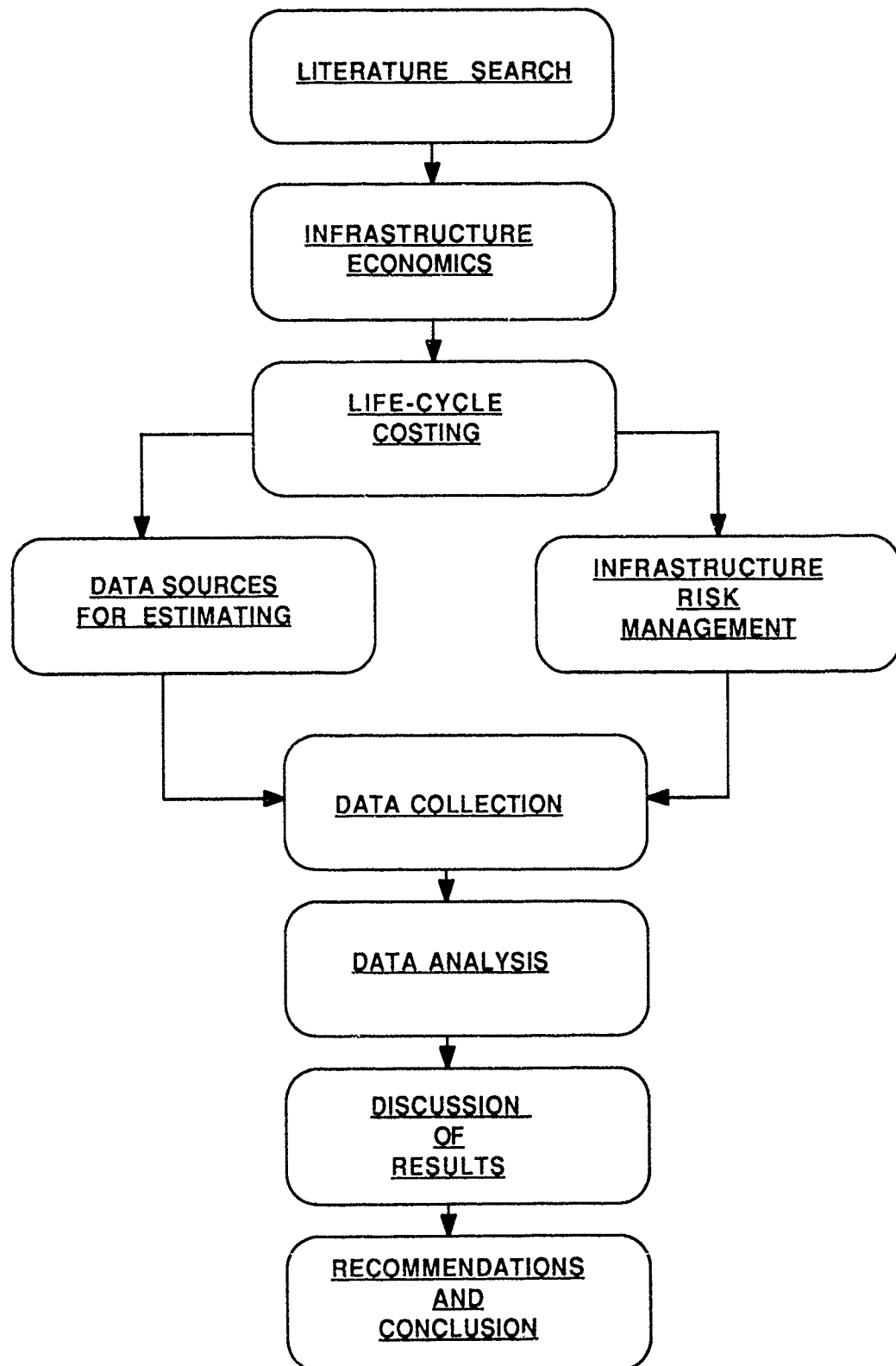


FIGURE 1.1 RESEARCH METHODOLOGY



## CHAPTER II      INFRASTRUCTURE ECONOMICS

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### 2.1 INTRODUCTION

Investment decisions in infrastructure systems result in significant expenditures and represent a major commitment of present and future resources. Therefore, it is essential that infrastructure decisions be rationally evaluated with regard to economic feasibility since it is largely the effectiveness of resource expenditures that lend or deny credibility to an organization's infrastructure investment program.

Correct application of economics, as a decision making tool in the area of infrastructure management, is paramount to selecting the best system to meet the established requirements at the lowest total cost. Unfortunately, many of those responsible for infrastructure related decisions are not well trained or educated in the use of infrastructure economics (National Council on Public Works Improvement 1988). Additionally, there are few training media available to assist in the application of economic life-cycle analysis to infrastructure related decisions (Ruegg and Marshall 1990). This lack of information results in substantial lost opportunity for improving the economic performance of selected infrastructure systems.

This chapter on infrastructure economics will discuss the required parameters used in economic analysis. These parameters

are essential for the purpose of selection of the optimal infrastructure system which minimizes the total cost of ownership while maintaining the required level of operational performance. Table 2.1 lists the steps involved with proper economic analysis.

- 
- STEP 1. DEFINE THE OBJECTIVE AND ESTABLISH THE CRITERIA.
  - STEP 2. IDENTIFY ALL FEASIBLE ALTERNATIVES WHILE CONSIDERING ALL APPLICABLE CONSTRAINTS.
  - STEP 3. DETERMINE THE LEVEL OF EFFORT WARRANTED.
  - STEP 4. SELECT A METHOD OF ECONOMIC EVALUATION
  - STEP 5. SELECT TECHNIQUE TO ACCOUNT FOR UNCERTAINTY OR RISK
  - STEP 6. COMPILE DATA AND FORECAST CASH FLOWS GENERATED FROM OWNERSHIP COSTS.
  - STEP 7. COMPUTE EACH ALTERNATIVE'S ECONOMIC PERFORMANCE.
  - STEP 8. COMPARE THE ECONOMIC CONSEQUENCES OF EACH ALTERNATIVE AND THE ASSOCIATED TRADEOFFS.

TABLE 2.1

Steps in the Economic Analysis Process

(Adopted from Ruegg and Marshall 1990)

---

## 2.2 TIME VALUE OF MONEY AND COST OF CAPITAL

In dealing with the economic impacts of competing alternatives, one must evaluate present and future costs in a manner that consistently relate the two as the basis for the economic decision. Today's dollar is not equal in value to a dollar at some time in the future since today's dollar can be invested immediately to start earning interest. Therefore, the amount of a present dollar is a function of the discount rate and the length of time invested. Inflationary impacts also change the value of money over time, but for infrastructure economics all costs are usually considered to be in constant dollars, i.e., in terms of general purchasing power of the dollar at the time of decision (Dell'Isola and Kirk 1983).

The "cost of capital", synonymous with "discount rate" or "opportunity cost", is the return on a cash investment foregone by investing in an infrastructure system. Use of the cost of capital as it pertains to the "time value of money" allows one to compute time-equivalent values for comparison of present and future costs on a consistent basis, i.e., the present value of a future repair cost may be found by multiplying the repair cost by the selected discount factor (Df):

$$\text{Present Value (\$PV)} = \text{Df} \times \text{future repair cost}$$

The discount factor is calculated as the reciprocal of 1 plus the selected discount rate (Dr) raised to the power of the total number of years to be discounted (t):

$$\text{Discount factor (Df)} = 1/(1+\text{Dr})^t$$

Time-equivalence formulas and precalculated discount factors are available from many sources (Brealey and Myers 1988).

The present value of all ownership costs can vary dramatically depending on the discount rate and adversely affect the analysis if not properly calculated. The proper discount rate should reflect the rate of return available on the next best investment opportunity of similar risk to the project in question; that is risk of uncertainties surrounding the owner, competition, or of the financial markets. Many firms establish periodic discount rates. For example, The Office of Management and Budget (OMB) in establishing the discount rate policy for all agencies of the Federal Government, except the Postal Service, prescribe a rate of 10% which represents an estimate of the average rate of return on private investments before taxes (Dell'Isola and Kirk 1983).

A method for calculating an appropriate discount rate for use in infrastructure economics is called the "Capital Asset Pricing Model". The model states that in a competitive market, the expected risk premium varies directly with the sensitivity of an investments return to market movements (Brealey and Myers 1988). An example calculation using the model may be seen in Appendix A.

The ability to compare present and future amounts on a time equivalent basis allows one to compare values of competing alternatives on a consistent basis. The discounting process using the correct discount rate (cost of capital) is critical to proper economic analysis since costs of ownership for infrastructure systems extend far into the future. Computation and equivalent comparison of all associated costs for each alternative are essential for proper evaluation of infrastructure systems.

### 2.3 INFRASTRUCTURE LIFE-CYCLE DURATION

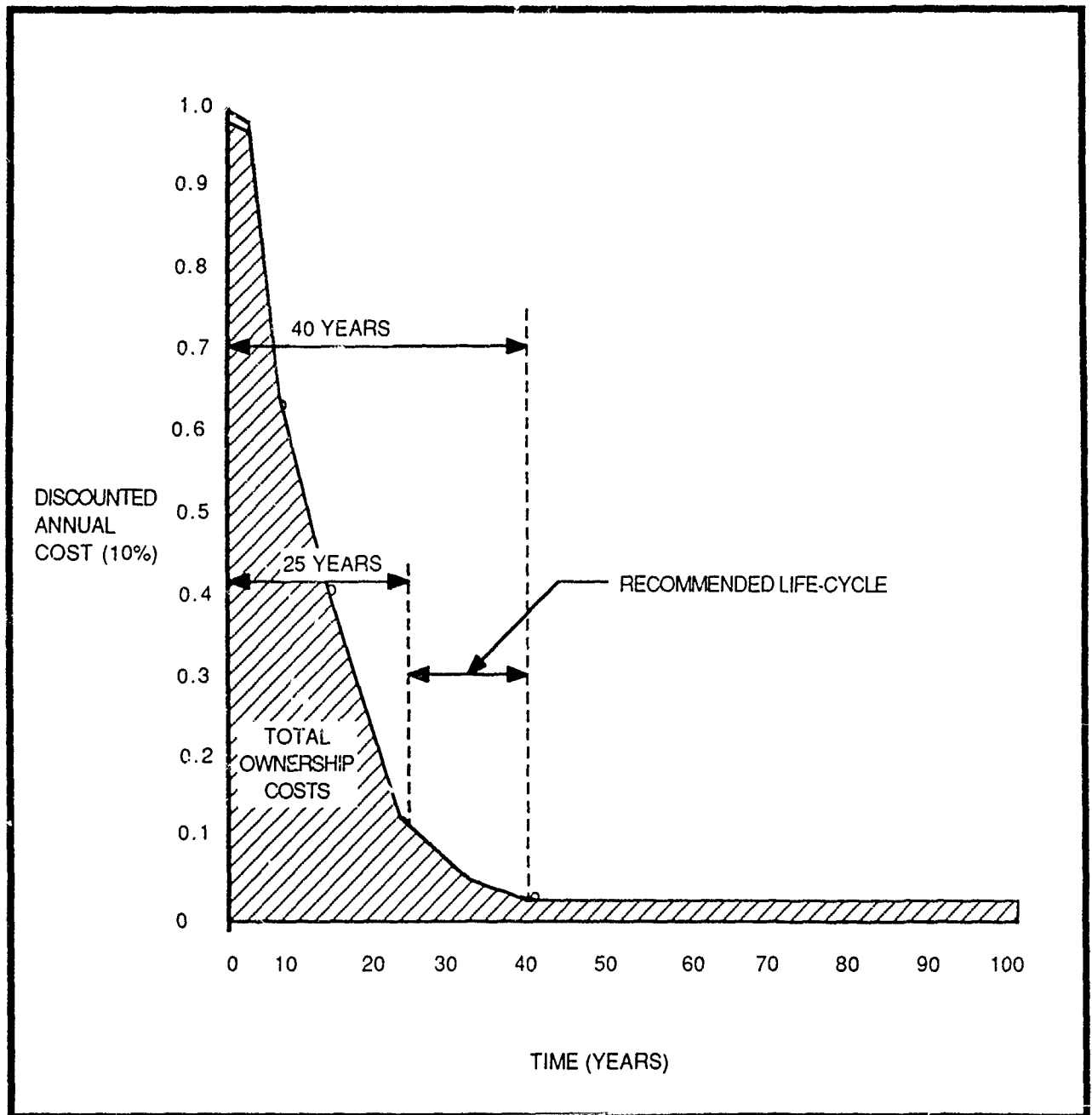
Another parameter to be determined when using economic analysis as a method to select the best infrastructure system is the duration of the life-cycle which will serve as the evaluation period for the analysis. The evaluation period is defined as the length of time over which all costs will be considered in making the decision. The life-cycle evaluation period should be established by the owner, not the design team, and be based on the goals and needs of a specific infrastructure system. Additionally, for private agencies, the depreciation period allowed by the Internal Revenue Service for tax reduction purposes plays an important role in selecting the service life or evaluation period. It should be noted that infrastructure systems constructed by developers for immediate resale may not consider life-cycle costing even though resale could be enhanced by explaining to potential buyers the favorable economic impacts of life-cycle costing considered during the planning and design phases of the infrastructure system. Similarly, owners interested in short term ownership, as opposed to long term institutionalized ownership, may be concerned only with short term revenues instead of minimizing long term ownership expenses. For purposes of this study, only long term ownership of non-revenue generating institutionalized infrastructure systems will be considered.

Selection of durations to be used in the analysis of competing infrastructure systems are normally selected to be the same for all

alternatives and are either the expected life of the system or the investor's holding period. However, there are cases where the duration selected must be the least common multiple of the alternative system lives in order for proper cost comparisons to take place, or the alternatives may be evaluated using equivalent annual costs (Ruegg and Marshall 1990).

If the duration selected is the infrastructure system's expected life, the most significant costs can be evaluated for economic purposes using a duration of 25-40 years (Dell'Isola and Kirk 1981). This is shown in Figure 2.1 using an annual cost for 100 years discounted at 10% to the present value. The area under the curve is the cumulative present worth of the costs, which at 25 years is 80% of the total cumulative cost.

INFRASTRUCTURE  
ECONOMIC LIFE-CYCLE



ECONOMIC LIFE-CYCLE SYSTEM  
FIGURE 2.1  
(SOURCE: DELL'ISOLA AND KIRK 1981)



## 2.4 OWNERSHIP COSTS

All costs to be incurred over the life of an infrastructure system are considered ownership costs.

"Construction costs are only a small portion of the total cost of ownership, and the building owner who recognizes that one will bear not only the initial acquisition costs but also the future costs of the systems operation, maintenance, and use should have an interest in controlling these costs". (Building Research Board 1991)

As shown in Figure 2.2, the categories for ownership costs include:

- o Initial acquisition costs (Cristofano and Foster 1986): all costs associated with the development of an owners project from conception through construction to include planning, design, engineering, construction and inspection.
- o Functional use costs (Ruegg and Marshall 1990): choice of designs may affect the system's functional use related to the performance of the intended functions. Labor costs and the productivity of workers within a building may be affected as well as the quality of services. Evidence that even small negative effects on occupant productivity can outweigh cost savings from lower maintenance and operating costs asserts that "healthy systems" contribute favorably to lowering the cost of ownership.

## OWNERSHIP COSTS

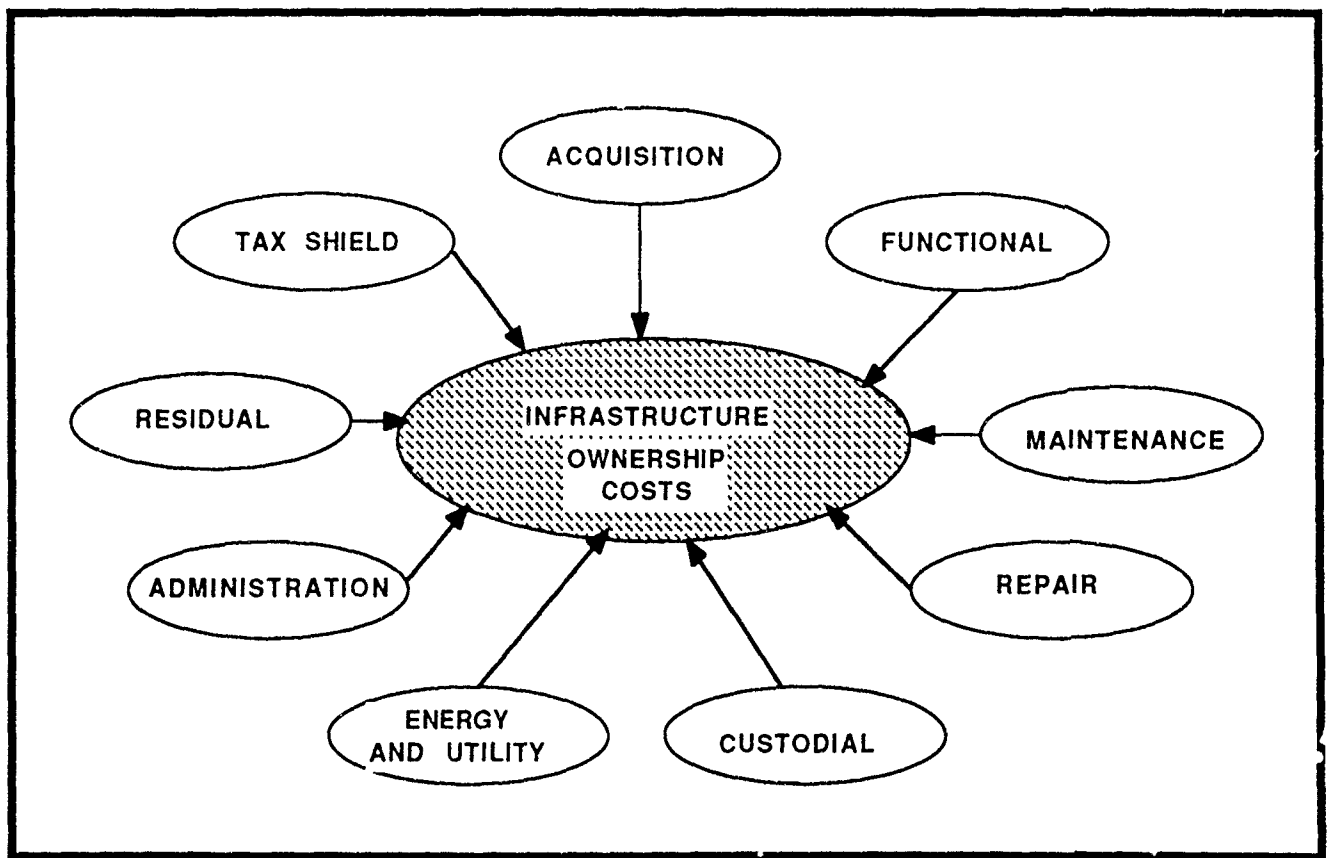


FIGURE 2.2 OWNERSHIP COSTS

- o Maintenance cost: normal and systematic preventive maintenance and operation, other than energy, to insure each system component contributes fully to the projected service life of the system.
- o Energy and Utility costs: charges for all forms of energy and other utilities consumed by the system.
- o Repair and Replacement: costs associated with unscheduled or emergency work in order to restore a system component to near original condition.
- o Custodial costs: cleaning and non-maintenance upkeep of the system.
- o Administrative costs (Riverso 1984): include property taxes, insurance premiums and other related costs.
- o Depreciation and Tax Shields (Dell'Isola and Kirk 1981): is a basis for deduction against income for calculating income taxes. Considered a "negative cost" for purposes of ownership since it is actually a benefit (only applicable to the private sector since public agencies are exempted from income taxes).
- o Residual costs (Ruegg and Marshall 1990): is the cost or benefit obtained from the system at the end of the life-cycle duration to include either resale, disposal and scrap, or terminal value.

### 3.1 INTRODUCTION

The requirement for a methodology which allows for the selection of the best infrastructure system with an emphasis on recognizing societies limited economic and natural resources was presented in the first part of this study. Chapter two introduced the required parameters for use of infrastructure economics and discussed the various categories of ownership costs. The focus of the study up to this point was to lay a foundation for presentation of a methodology for solution of the dilemma of diminishing resources, and also to offer a method of assessing data on construction and maintenance items for a particular infrastructure system in order to discuss the impacts on the total cost of ownership.

Life-cycle costing is a methodology by which competing alternatives may be analyzed and evaluated to insure selection of the best alternative which yields the lowest cost of ownership over the predetermined life of the system while insuring all functional and operational requirements are met. Life-cycle costing is an economic evaluation process developed to assist in defining and then deciding among alternative investments or operating strategies.

### 3.2 HISTORICAL DEVELOPMENT

Written records on developments of life-cycle-costing are vague and somewhat inconclusive, but it is believed that 1930 was the first year for what became at that time the authoritative reference for engineering economics, "Principles of Engineering Economy" by Eugene L. Grant. Shortly thereafter, the Comptroller General of the United States published a government reference on life-cycle costing for use in the procurement of machinery. It supported an analysis of bids based not only on acquisition costs but also on operations and maintenance items (Dell'Isola and Kirk 1981).

The American Telephone and Telegraph (AT&T) published its first edition of "Engineering Economy" in 1952 to introduce engineering economics for the designers use. This document states (Dell'Isola and Kirk 1981):

"It is the responsibility of the engineer to determine the plan which will meet the physical requirements in the most economical manner.... In the telephone business (and other industry) the company has not only the desire, but the obligation to provide service. Therefore, the only engineering question is; How can good service be provided at the overall lowest cost...."

It was not until the 1960's that the construction industry began to formally recognize the application infrastructure economics. The Building Research Institute was the first to sponsor a conference on the subject, titled "Methods of Building

Cost Analysis". Also during the 1960's the Logistics Management Institute released a study which concluded that had life-cycle costing been included in bid analysis, many contracts would have been awarded to other than the low bidder (Dell'Isola and Kirk 1981). This highly influential report resulted in a 1971 Department of Defense directive on the application of life-cycle costing in the acquisition process.

Many other public and private agencies have implemented procedures for the application of life-cycle costing having recognized the total cost of ownership includes much more than the initial cost of acquisition. While there are no generally applicable or accepted procedures or principles for use in controlling the cost of ownership, the guidelines prepared by the Department of Energy (DOE), National Institute of Standards and Technology (NIST), and the US Army's Construction Engineering and Research Laboratory (CERL) have taken the lead in providing information on life-cycle costing policies and procedures.

### 3.3 CONCEPTUAL DEFINITION

Life-cycle costing is a fundamental concept in infrastructure planning and management which operates under the premise that every aspect, from concept through disposal, of an infrastructure system has an associated cost. It can be defined as the total cost of ownership over the predetermined life of a specific infrastructure system.

Life-cycle costing is a decision making technique for management, a tradeoff tool, and more importantly a philosophy that is gaining importance in the construction industry. Consumers are increasingly more concerned about maintenance and repair costs over the period of ownership. Consequently, the emphasis of selecting a system based solely on initial acquisition cost is becoming increasingly less valid as a method to choose between competing alternatives (Patton 1988). Life-cycle costing can be used to establish priorities for competing alternatives under limited financial resources, or used as a method to make comparisons between various infrastructure systems.

Alternative infrastructure systems are characterized by the different patterns of costs forecasted to be incurred over a specific evaluation period, ownership costs such as those discussed in Section 2.4. Life-cycle costing seeks to evaluate the different patterns on comparable terms using the economic analysis parameters discussed in Chapter II.

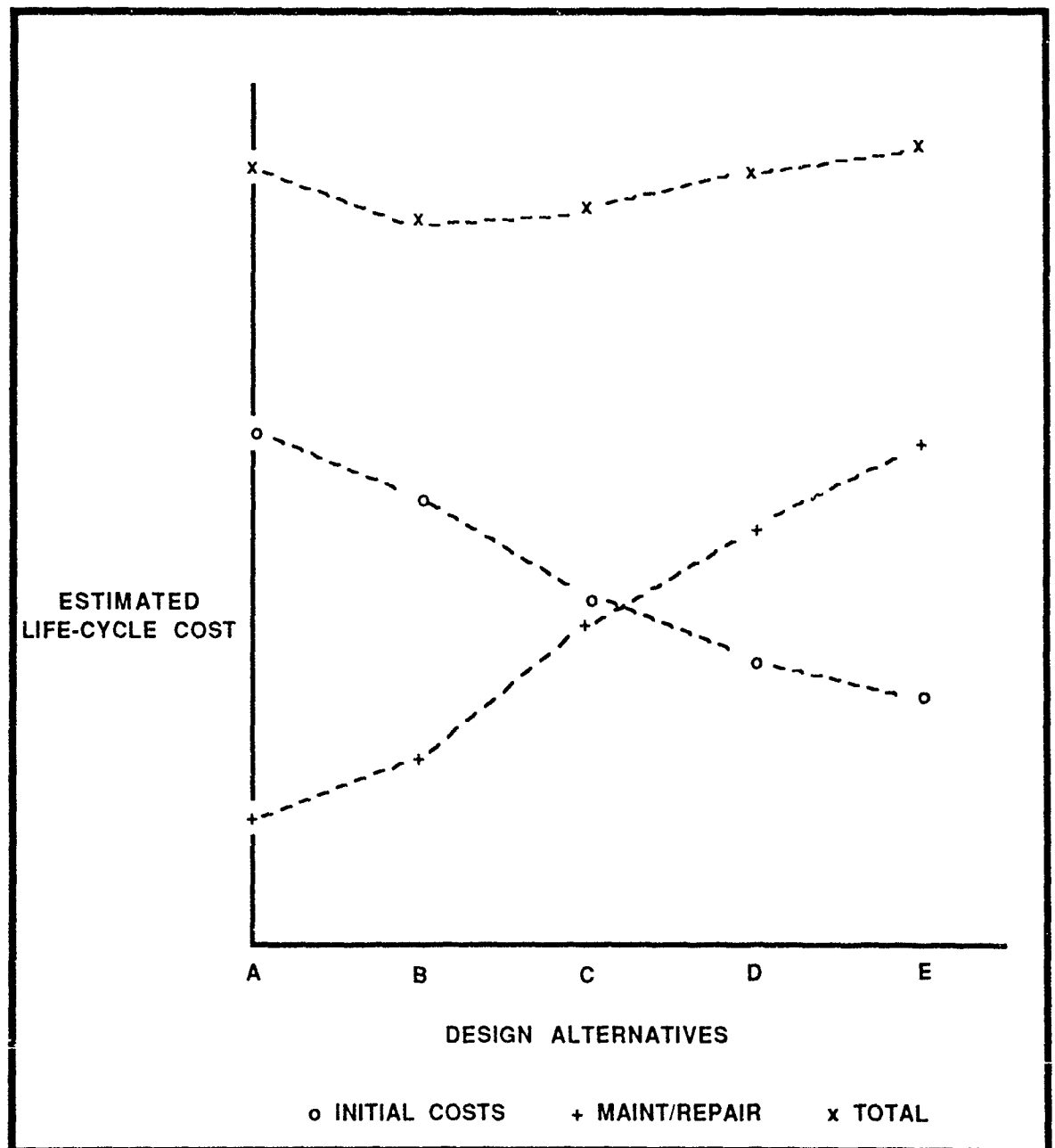
"Alternatives are typically defined to illustrate in a systematic way some tradeoff between first costs (i.e., for construction or equipment) and future recurring costs (i.e., for maintenance and energy consumption). The analysis is often undertaken with an expectation that an alternative can be found that will generate the lowest life-cycle cost"(Building Research Board 1991).

As can be seen in Figure 3.1, the highest initial construction cost usually results in lower maintenance and repair cost due to use of higher quality materials with a corresponding longer service life, and the lowest initial construction cost usually results in a higher maintenance cost. Life-cycle costing attempts to find the alternative with the lowest cumulative ownership costs over the selected duration while meeting all the established requirements.

The versatility and flexibility of life-cycle costing allows the user to analyze costs in terms of the environment today and the constantly changing factors. It's usefulness and value are derived from a growing awareness to select the best system to meet the established requirements at the least total cost.



# TRADEOFFS FOR LIFE-CYCLE COSTING



TRADEOFFS TO MINIMIZE LIFE-CYCLE COSTS

FIGURE 3.1

(SOURCE: BUILDING RESEARCH BOARD 1991)

### 3.4 PROGRAM DEFINITION

Life-cycle costing is a program through which all costs can be first identified and then quantified for all aspects of ownership over the selected life of an infrastructure system. The steps involved in life-cycle costing follow closely those discussed in Section 2.1 for infrastructure economics.

The first step is to provide the objective for the analysis which will establish the requirements in order to select among the competing alternatives - what is desired and required.

The second step fixes the criteria for the analysis. The criteria will set the duration over which the analysis will be conducted (see Section 2.3). The other important economic parameter established at this point is the cost of capital or discount rate which allows all future costs to be converted to a present value. As discussed in Section 2.2, it is necessary to bring all future outlays for the competing alternatives to a common reference point, normally the present value, to allow comparable comparisons of total costs. For example, whereas one alternative may seem more cost effective than another because it has a lower acquisition cost, it may likely be more costly to own over the life of the system when considering future maintenance and repair costs.

During the third step of the analysis, all costs for each alternative must be forecasted and estimated. In order to accurately establish certain ownership costs, various resources such as labor, materials, and energy must be estimated even though

these costs are difficult to quantify and fluctuate dramatically over time.

The fourth and final step in life-cycle costing involves using the established criteria to discount all ownership costs to a common reference point, most commonly to the present value of money today (time zero), using the net present value technique (NAVFAC P442 1986). By bringing all competing alternative ownership costs to a common period in time, comparisons can be made and the best system determined that has the lowest total ownership costs. Unfortunately, infrastructure systems are too often acquired on the basis of initial acquisition costs for reasons of budgetary restrictions, political pressures, or lack of understanding on life-cycle costing; but times are changing - they must.

### 3.5 PRESENT VALUE COST MODEL

Many methods of economic analysis exist, but the most widely accepted for life-cycle costing is the discounted present value approach (Ruegg and Marshall 1990). Using this approach, all costs are discounted to one lump sum at the beginning of the evaluation period using discount factors and time-equivalence formulas as discussed in Section 2.2. The object of a present value cost model is to be able to identify and quantify in specific terms as many cost activities as possible or necessary to best evaluate the given alternatives within the established parameters. These models may be simplified using any personal computer system to provide an even more effective means of evaluating the selected alternatives. The fundamental equation underlying a total life-cycle cost model can be expressed as shown below (Bromilow and Pawsey 1987):

- if the present discounted total life-cycle cost over period "T" measured from time of acquisition is "St", then

$$S_t = C_0 + \sum_{i=1}^n \sum_{t=1}^T C_{it}(1+r_{it})^{-t} + \sum_{j=1}^m \sum_{t=1}^T C_{jt}(1+r_{jt})^{-t} - d(1+r_d)^{-T}$$

- where  $C_0$  is the acquisition cost at time  $t=0$ , previously defined in Section 2.4;  $C_{it}$  is the annual cost at time  $t$  ( $0 \leq t \leq T$ ) of support function  $i$  ( $1 \leq i \leq N$ ) which can be regarded as continuous over time, such as maintenance, custodial, and energy;  $C_{jt}$  is the cost of a discontinuous support function  $j$  ( $1 \leq j \leq M$ ) which occurs

at various intervals of the life-cycle, such as unscheduled repairs or replacements;  $r_{it}$  and  $r_{jt}$  are discount rates applicable to support functions  $i$  and  $j$ , respectively, over time period 0 to  $t$  and are both normally the cost of capital discussed in Section 2.2;  $d$  is the residual value and  $r_d$  is the discount rate applicable to the residual value from time 0 to  $T$ . Also if  $c_i$  is in current dollars, then  $r_i$  will be the nominal discount rate, and if  $c_i$  is in constant values, i.e. deflated, then  $r_i$  will be the real discount rate. Similar considerations apply to the other factors.

## CHAPTER IV      LIFE-CYCLE COST ESTIMATING

---

### 4.1 DATA SOURCES

Finding the alternative which offers the lowest life-cycle cost requires a good understanding of the technical factors underlying the tradeoffs being considered, a certain amount of ingenuity and judgement, and reasonable estimates of the various ownership costs involved (Building Research Board 1991). The technical factors are derived from education and training and involve the principles of economics and engineering, while ingenuity and judgement are developed with time and rely more on one's experience and personality. The final requirement for finding the minimum life-cycle cost, reasonable estimates of the various ownership costs, can be more easily and accurately obtained through the use of database development and application.

Before life-cycle analysis can be used to determine the best alternative, projected costs for future outlays must first be identified and quantified for each proposed alternative. The most difficult aspect of finding the total life-cycle cost is forecasting and then estimating the various costs of ownership; in particular, the costs of maintenance and repair items. Appendix B includes typical life-cycle costing estimating forms used to assist in identifying the various categories of ownership costs.

Sources of data for use in life-cycle costing are identified

in Appendix C. In the maintenance and repair categories of ownership costs, significant recent advances have been made. Since the maintenance and repair categories are the most difficult to forecast due to lack of sufficient data and historical records, and the categories on which data collection for this study are focused, the remainder of this section will concentrate on the two most accepted methods by which maintenance and repair costs can be developed for life-cycle costing analysis. The two methods for developing such costs include the use of historical data and engineered or scientific data.

#### 4.1.1 HISTORICAL DATA

The first database described as an industry first attempt was developed in 1983 by Dell'Isola and Kirk. Adequate historical data was not available at that time requiring the authors to gather information from several industry sources in order to form the best available collection of data (Dell'Isola and Kirk 1983). As shown in Appendix D, data was presented on annual maintenance costs, replacement lives, and cost of replacement, all as a function of initial acquisition costs. Another database was attempted by the Army Corps of Engineers in 1985. Results of that research concluded that collection of data on repair and maintenance costs for U.S. Army installations could not be accomplished since historical records lacked the necessary amount of detail to develop a complete and useable database for life-cycle costing. Many public and private agencies have improved upon record keeping techniques in order to develop databases for use in life-cycle cost estimating. However, historical data for use in estimating may not be applicable for some time until sufficient data is available for collection and analysis.

In the opinion of many experts, historical cost data is difficult to collect and analyze due to the dissimilarity of infrastructure systems to include geographic, functional, and operational differences (Building Research Board 1991). Additionally, expenditures for maintenance and repair items are more often subject to the personal judgement of owners and managers



than are other ownership costs (Ruegg and Marshall 1990). Consequently, these costs vary considerably even for similar types of systems. For this reason, even if sufficient historical data existed, use of this data for maintenance and repair forecasting would be the subject of much scrutiny. However, use of historical data as a means to evaluate life-cycle costing applications to prove its validity, could be achieved through correlation of construction and maintenance/repair items incurred thus far in the life of a particular system.

#### 4.1.2 BOMA EXPERIENCE EXCHANGE REPORT AND R.S.MEANS DATA

The "Downtown and Suburban Office Building Experience Exchange Report (EER)" published by the Building Owners and Managers Association International (BOMA) publishes results of annual samples of building ownership costs for items in the areas of mechanical, electrical, and heating/ventilation/air conditioning (HVAC). Included are various maintenance and repair items broken down by geographic location, city population, age, and size of the infrastructure system.

The R.S. Means Company also provides similar maintenance and repair data in various publications. A unit price section for specific ownership costs lists data for various infrastructure systems.

Both the BOMA Experience Exchange Report and R.S.Means data can be used to assist in life-cycle cost estimating in the areas of maintenance and repair. However, most sources used for life-cycle cost forecasting are not likely to be identical to the selected alternatives, but are possibly the best that can be accomplished given the limited availability of resources in this area.

#### 4.1.3 CERL DATABASE

The US Army Corps of Engineers Construction and Engineering Research Laboratory (CERL) located in Champaign, Illinois has developed an engineered database for forecasting the ownership costs of maintaining infrastructure system components.

"The database has been tested by a number of military installations and contractors. It is accessible by cost reports and by computer software. It is the most comprehensive, consistent, and well documented database we know for estimating maintenance and repair costs" (Ruegg and Marshall 1990).

The approach used in the development of this database is based on Engineered Performance Standards (EPS) described by the following:

- o Determine scheduled maintenance using manufactures recommendations and prior experience, and forecast repairs by determining the frequency of repairs using established failure rates for specific components.
- o Breakdown each maintenance and repair item into work activities with the associated manpower components for each activity using a predetermined average time period to perform the specific task.
- o Determine material and equipment requirements for the forecasted maintenance or repair item.
- o Calculate total resource requirements (material, equipment and manpower) for each year of the system's life.

The CERL database covers the four primary infrastructure subsystems of architectural, plumbing, electrical, and HVAC which are broken down into individual components and repair items using the procedure described above (Neely May 1991). The database can provide costs for components of the various alternatives (i.e., roofing alternatives for built-up, slate cement asbestos, tile, shingle, and other roofing materials).

The labor rate portion of the database uses the time motion study concept to which one applies one's own wage rates. Additionally, the database allows for various pricing indices in order to accommodate for geographic differences and varying levels of use. These features of the database make it possible to evaluate many different types of infrastructure systems at many different locations in both the public and private sectors. Appendix E lists research progress by CERL and the published reports for this highly touted tool for life-cycle costing and resource planning. Additionally, the author intends to implement the CERL life-cycle costing data base during the next tour of duty at the Great Lakes Naval Training Center while filling the position of Staff Civil Engineer.

#### **4.2 INFRASTRUCTURE RISK MANAGEMENT**

With the first development of a database for infrastructure life-cycle costing being attempted only eight years ago (Dell'Isola and Kirk 1983), it is fair to say life-cycle costing is relatively new in the area of infrastructure management.

One of the principal reasons, other than being relatively new, that life-cycle costing has not progressed in this area, may be that many in the construction industry have the impression the cost estimates developed for purposes of decision making using this type of analysis are somewhat unreliable. Understanding it is difficult to use life-cycle cost analysis with a high degree of precision due to the uncertainties of forecasting future ownership costs for maintenance and repair items, makes it necessary to incorporate "risk management" into investment decisions of infrastructure systems.

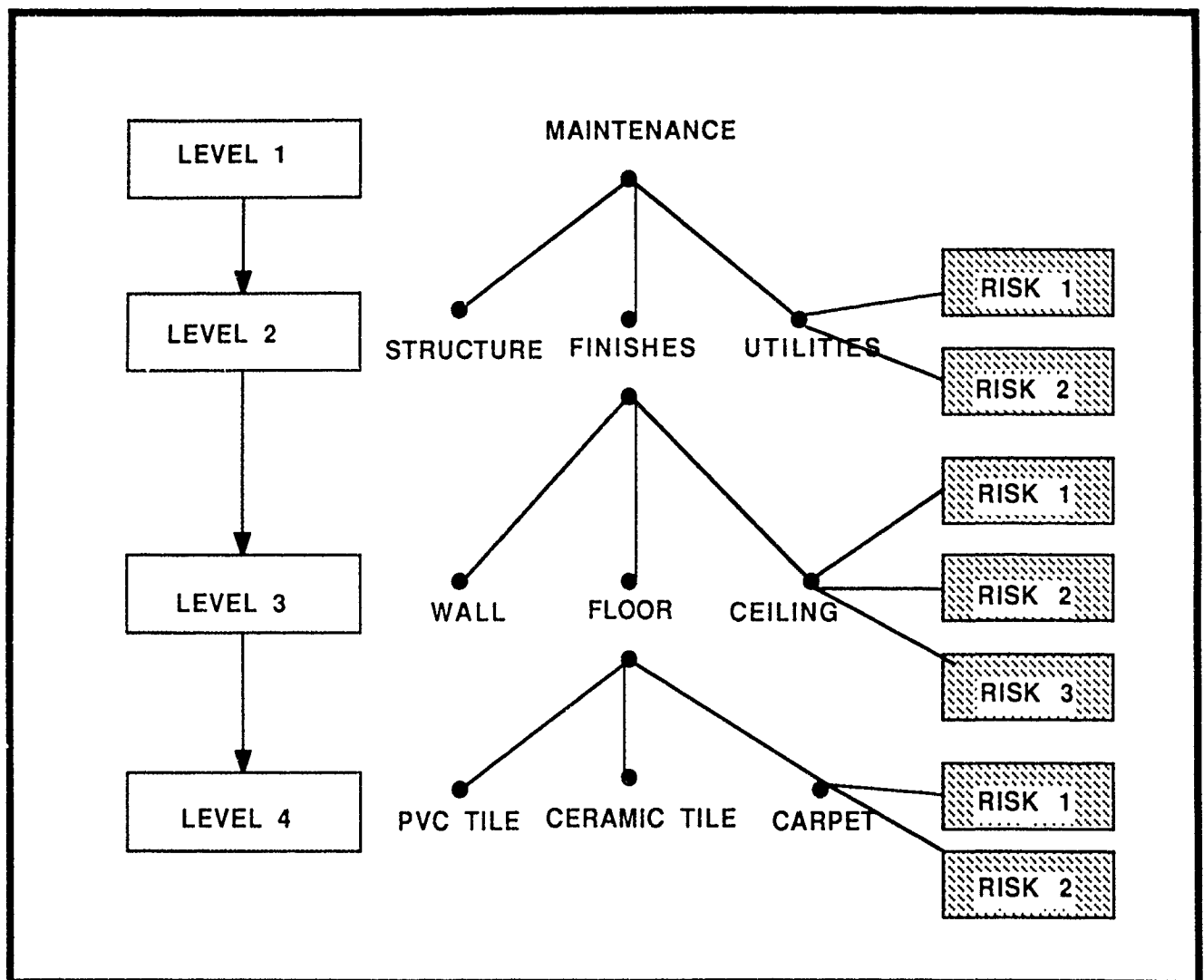
Risk management as applied to life-cycle costing of infrastructure systems refers to the assessment of and reaction to the risk of uncertainty that will inevitably be associated with future ownership costs (Flanagan 1987). By incorporating risk management into the decision makers analysis, many of the uncertainties can be minimized to provide a more reliable cost forecast and thereby enhance the application of life-cycle costing in the area of infrastructure management.

#### **4.2.1 RISK IDENTIFICATION**

An integral part of life-cycle costing is development of feasible alternatives given the requirements for a specific type of infrastructure system. The tradeoffs generated by choosing one alternative over another have inherent risks involved when considering the costs of maintenance and frequency of repairs associated with each alternative. The first part of managing the risk is to identify the risk associated with each alternative being considered.

As can be seen in Figure 4.1, one such method to identify the risk is the decision tree approach (Flanagan 87). Maintenance costs can be subdivided in a hierarchial manner, each level of the hierarchy being associated with increasingly more detailed cost information. Once all levels of risk have been identified for each alternative, the decision maker's risk attitude can be incorporated into the decision process for selection.

## DECISION TREE



DECISION TREE AND RISK IDENTIFICATION

FIGURE 4.1  
(ADOPTED FROM FLANAGAN 1987)

#### 4.2.2 RISK ATTITUDE

A decision maker's risk attitude is measured by a willingness to tradeoff during analysis of competing alternatives given the associated risk exposure for each alternative. Risk exposure examines the probability profile of obtaining certain costs for each alternative system. For example, by knowing the probability of obtaining certain repair costs, as established from prior experience and manufactures data, for competing heat distribution systems, does one purchase the system with the higher acquisition costs to gain a lower probability of repairs or accept the tradeoff for another alternative of lower acquisition cost with a higher probability for repair costs over the life of the system?

Effective life-cycle costing must take into account the risk and uncertainties for each competing alternative if economic efficiencies are to be obtained in the management of infrastructure systems.

There are two general approaches to incorporate risk attitude into life-cycle cost analysis (Ruegg and Marshall 1990). The first is to make a decision based on the subjective or intuitive perception to accept the degree of risk shown in the probability profile for the selected alternative. If the investment decision is to reject or accept a system or to select the best system among the competing alternatives, then this approach is likely sufficient even though it lacks any way to measure the risk attitude involved with the selection. There are cases where the selected alternative



has the highest degree of associated risk but the lowest life-cycle cost. Under this scenario, there must be a second or formal approach to quantify the risk attitude when evaluating the alternatives. Detailed discussion on a formal method to quantify risk attitude is not considered for purposes of this study. However, recent literature discusses the use of "the utility theory" as a formal method to quantify risk attitude (Ruegg and Marshall 1990).

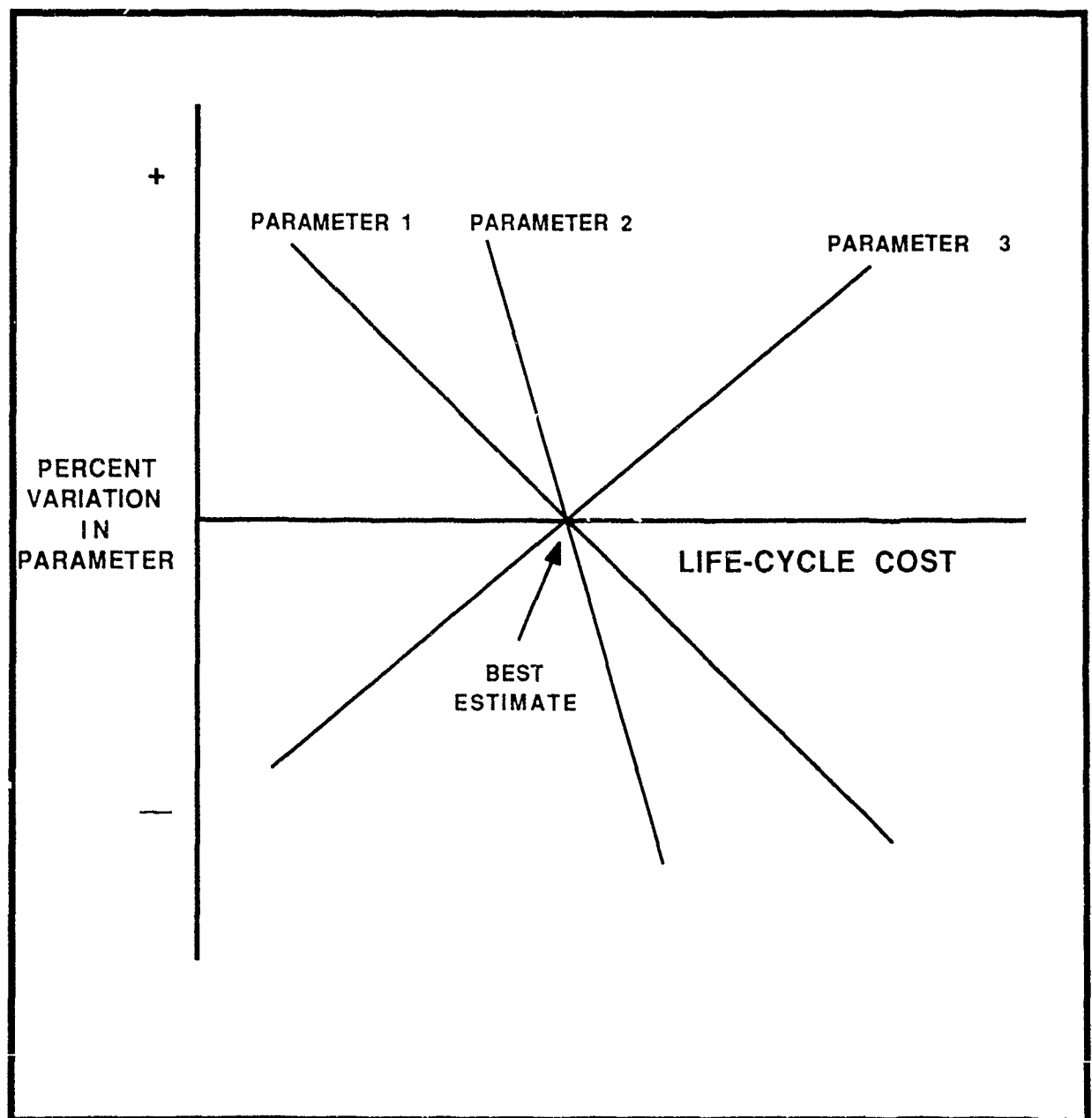
#### 4.2.3 SENSITIVITY ANALYSIS

As has been discussed, the principal objective of life-cycle costing is to analyze and select among competing alternatives the best system to achieve the required results for the least cost of ownership. Selection of one alternative over another may in fact change by varying one or several of the many factors considered when evaluating the alternatives (i.e., acquisition costs, maintenance costs, cost of capital, duration period, etc.).

Sensitivity analysis is a modelling technique that answers the "what if" questions of changing a specific factor and the impacts of the change on the overall analysis. Sensitivity analysis although univariate, as opposed to probability analysis which treats all variations of the factors at the same time in probability distributions, is likely to prove the more applicable and understandable in risk analysis (Flanagan 1987).

An effective graphical representation of sensitivity analysis is the spider diagram (Ruegg and Marshall 1990). By allowing various factors to vary by a specified amount, the impact on the life-cycle analysis can be determined. As shown in Figure 4.2, the flatter the line the more sensitive life-cycle costing is to a specific parameter. For example, the impact of a change in parameter 3 would be much greater than that of parameter 2. Additionally, by including probability contours, a range of variation for a parameter can be plotted on the spider diagram.

## SPIDER DIAGRAM



SENSITIVITY ANALYSIS SPIDER DIAGRAM

FIGURE 4.2

(SOURCE: FLANAGAN 1987)

Sensitivity analysis as a management and decision making tool provides a definitive method for making a selection given competing alternatives. Even though this type of analysis does not provide an absolute solution, selection of the best alternative using this type of analysis is the kind of judgement that managers should be expected to make.

### 5.1 INTRODUCTION

The study thus far has discussed life-cycle costing as a method to analyze competing alternatives in order to select the best alternative to meet the established requirements at the lowest total cost of ownership. Additionally, it offered that conservation of both economic and natural resources could be achieved through a greater investment at acquisition in higher quality materials and equipment which in turn should reduce the amount of future maintenance and repair outlays.

Unfortunately, the acquisition of infrastructure systems appears to carry much more importance than future costs in the maintenance and repair categories of those same systems even though industry experts have offered that future outlays may total much more than the initial cost of construction over the life of a particular system (Building Research Board 1990).

Infrastructure related budgets are often established based on maximum limits for construction expenditures. If costs can not be kept within budget, the project may be canceled, or worse yet, the project's cost may be reduced through substitution of lower quality materials and equipment. When the constraint of the budget or capital rationing is the controlling factor, life-cycle costing may not be realizable. As a result, the selected system may generate

higher maintenance and repair costs. One may intend on correcting the shortfalls at a later date or accept the increased ownership cost as the price one must pay for the current funding deficit. In the case of public infrastructure systems, the higher cost of ownership is passed on to the taxpayer and in many cases compounded by deferral of the required maintenance and repair items. Deferral of maintenance and repair efforts lead to premature deterioration and failure of infrastructure systems and system components, accelerates increases in ownership costs, and causes potential threats to safety and health (Building Research Board 1990).

There has been little effort in providing results on performance of in service infrastructure systems to systems in the planning and design stages (Building Research Board 1990). This information could show how life-cycle costing influences the maintenance and repair requirements of infrastructure systems. Since the relationship between acquisition costs and future maintenance and repair costs are difficult to describe, correlation of historical construction and maintenance/repair costs for specific infrastructure systems could assist in justifying the need for life-cycle costing.

This chapter proposes to discuss collection and analysis of data for three separate infrastructure systems in order to discuss some of the various maintenance and repair items and their impacts on the total cost of ownership. An assessment will also be made as to what extent the specific maintenance and repair items provide the potential benefit of a feedback mechanism for future designs.

## 5.2 DATA COLLECTION

Collection of data for discussion of historical construction and maintenance/repair items for the following infrastructure systems was conducted through on site interviews, facilities inspection summary sheets, and review of previous studies. However, initial acquisition costs were available for only one of the three proposed systems and historical maintenance and repair records were insufficient for statistical correlation of incurred ownership expenses on all three systems.

### Facilities Data

The facility infrastructure system selected was constructed in 1968-70. The function of the facility is classroom and office space. The structure is three levels of reinforced concrete with concrete flat plate construction throughout. The exterior of the structure is brick faced. The outside access to the upper two levels is provided by concrete ramps. The roof component is concrete deck with a built-up roofing membrane.

Since the historical construction records are retained in the Federal Archives and not easily retrieved, correlation of the two selected repair items to the initial construction activities was not feasible. As described in Appendix F, the two specific items selected for analysis were repairs to the roof and concrete ramp components. At seven years into the life-cycle of this facility, repairs to the roof deck and replacement of the entire roofing

membrane at a cost of over \$ 200K was identified. Additionally, the exterior concrete walkway ramps were in need of \$ 150K repairs at a point of only seventeen years into the facilities life-cycle.

#### Steam Heat Distribution System

Collection of data for life-cycle cost analysis for purposes of this study was obtained from a previous study completed in 1986 by the Ralph M. Parsons Company. The purpose of the Parsons study was to conduct a comparison between direct buried conduit and concrete shallow trench heat distribution systems to demonstrate the economic differences in ownership costs over a 25 year life-cycle. A direct buried system consists of two separate insulated conduits (feeder and return lines) buried under earth cover in a common trench. A shallow concrete trench system is basically the same as the direct burial but instead is placed in a concrete trench with removable cover flush with the adjacent ground surface allowing for easier maintenance and repair. Initial construction costs were obtained by collecting data from local suppliers and contractors. However, no mention of actual historical construction costs is made. Historical maintenance and repair cost data was not available. "It was attempted to collect cost data from maintenance logs and records. It was found, however, that such records were very sparse or nonexistent..." (Parsons 1986). Since insufficient data existed, repair costs were calculated based on failure rates for each system in combination with the material, equipment, and



labor required to locate and make repairs. Construction costs are shown in Table 5.1 with repair costs given in Table 5.2. Appendix G describes the derivation of the cost figures for this system.

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<u>Pipe Dia (in.)</u>	<u>Direct Buried</u>	<u>Shallow Trench</u>
1	\$ 816,288/mile	\$ 1,448,040/mile
1.5	843,586	1,456,382
2	848,589	1,456,382
3	919,882	1,564,200
4	961,699	1,610,875
6	1,202,256	1,849,003
8	1,463,193	1,934,539

---

Heat Distribution System Construction Costs  
Table 5.1

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<u>Year</u>	<u>Direct Burial</u>		<u>Shallow Trench</u>	
	<u>Failures/mile</u>	<u>\$/mile</u>	<u>Failures/mile</u>	<u>\$/mile</u>
0-7	0	0	0	0
8	.10	440	0	0
9	.21	923	0	0
10	.34	1494	0	0
11	.42	1846	0	0
12	.50	2198	.02	27
13	.59	2593	.04	55
14	.67	2945	.05	69
15	.76	3340	.07	96
16	.83	3648	.07	96
17	.88	3868	.08	110
18	.95	4175	.08	110
19	1.0	4395	.09	123
20	1.06	4659	.10	137
21	1.10	4835	.10	137
22	1.15	5054	.11	151
23	1.20	5274	.12	164
24	1.24	5450	.12	164
25	1.29	5670	.13	178

---

Heat Distribution Repair Costs  
Table 5.2

### Pavement System

The third infrastructure system considered for this study is Portland Cement Concrete Pavement (PCC). Review of a 1990 study of rigid pavement maintenance and repairs provides the information for this qualitative analysis (Jaspers and Sinha 1990). While the 1990 study does not offer historical costs incurred thus far in the life of the pavements, it does offer a method of life-cycle costing which allows one to compare alternatives that do not necessarily have the same service life.

Historical maintenance and repair cost information was insufficient for use in the PCC study so collection of the required data was obtained through other methods.

"After a few installation interviews, it was found that much of the cost information was not available. Consequently, unit costs were estimated in consultation with facility engineers and local contractors" (Jaspers and Sinha 1990).

Yet another case of the requirement to recreate the required data since historical cost records were insufficient. For purposes of analysis of this pavement system, historical data correlation was not feasible. Fortunately, for qualitative discussion of the life-cycle cost model presented in the 1990 PCC study, data analysis was not required.

### 5.3 DATA ANALYSIS

#### Facilities

Correlation of the two selected repair items, roof and ramp repairs, to the initial construction costs could not be made since historical records were not available. In addition to the direct costs of \$ 200K for the roof repairs which includes deck repairs and roofing replacement, extensive damage was also done to the electrical systems, interior walls and ceilings, and interior finishes. These repairs should also be considered when determining the impact on the total cost of ownership caused by this repair item. The exterior concrete ramps are 12 x 150 feet and have electrical heaters embedded in the concrete to keep the ramp free of ice and snow in the winter months. The ramp repairs identified include replacement of the heaters and significant structural repairs to the concrete walkway and supporting structure.

The projected service life of built-up roofing is 20-25 years, concrete roof and floor (ramp) slabs have a service life of 40-50 years (Dell'Isola and Kirk 1983). For the roof system of this facility to have a life of only seven years and the concrete ramp to have a service life of only seventeen years, as opposed to the projected service lives of 25 and 50 years, respectively, it is fair to say these two repairs have a significant impact on the total ownership costs of this infrastructure system.

### Heat Distribution System

Analysis of the direct burial and shallow trench steam heat distribution systems was conducted using life-cycle cost computations on the data described in Tables 5.1 and 5.2 (Parsons 1986). Results indicate, on a 25 year life-cycle basis the direct buried conduit system is more economical than the shallow trench when considering the total cost of ownership. In analyzing the lotus 1-2-3 life-cycle cost computations, shown in Appendix H, one can see that the initial cost of construction is the dominating factor in the analysis. Note also that operating costs are nearly the same, and even though the direct burial has higher maintenance costs, the maintenance costs are relatively low when compared to the construction costs.

It is interesting to note that a similar study was conducted one year earlier on the same two types of systems and provided opposite results. That is, the shallow trench proved the most cost effective over the 25 year analysis since the study presented construction costs to be nearly the same for both systems (PAN AM World Services 1985).

### Pavement

The analysis procedure developed for this infrastructure system was an equivalent uniform annual cost life-cycle approach which offers ranges of estimates for competing alternatives with different service lives such as maintenance, repair, or

reconstruction (Jaspers and Sinha 1990). While the Pavement study did not allow correlation of historical construction and maintenance costs, it does offer a unique managerial approach to pavement management. Through use of the PAVER management system, networks of roadways can be assessed for a pavement condition index which allows for prioritization in scheduling and resource allocation. Appendix H describes the life-cycle costing procedure that could possibly be adapted for management of all infrastructure systems.

#### 5.4 DISCUSSION OF RESULTS

Analysis of the performance of existing infrastructure systems to facilitate feedback for the design of other systems, and as a method of assessing life-cycle costing applications, can be a valuable tool in the area of infrastructure management.

The discussion on the facility portion of this study, while focusing on only two of several repairs to be incurred over this facility's life-cycle, offers specific issues worth addressing as potential feedback of lessons learned for consideration in future decision making. Pertaining to the roof component, one should wonder why such a short service life of seven years was achieved as compared to a projected service life of 25 years. Quality of roofing materials or workmanship are two potential areas worth investigating. Another issue to be addressed should be the economic impacts of failing to properly repair the roof component upon initial identification of the problem. The identified repair item was not resolved until five years after identification. Instead, several insufficient interim repairs were attempted and resulted not only in poor use of available funds but also increased interior water damage thereby compounding an already significant repair item. As was the case with the roof component, one should question why the concrete ramp had such a short service life of seventeen years as opposed to the projected life span of 50 years. Another issue pertaining to the ramps should be the exterior

ingress; was this an absolute requirement or would have interior staircases been sufficient for access to the upper floors. Certainly in a Northern climate interior ingress should have been at least an alternative to compete with embedded concrete heaters which provide no feasible method to repair or replace.

In the discussion on heat distribution systems, results indicate the direct burial system was the most economical over a 25 year analysis period even though it generated higher repair costs. Since material and labor costs are substantially higher for construction of the shallow concrete trench, while maintenance and repair costs are relatively insignificant for both systems over the 25 year analysis period, one should question other parameters used in the analysis of the two systems. During the analysis it was found that concrete shallow trenches have shown service lives of 50 years to be feasible. A service life of 25 years was found to be a good range for the direct burial system, but some have operated in excess of this projected service life at excessively high repair costs (Pan Am World Services 1985). The different life expectancies of the two systems should lead one to inquire as to why both were evaluated on a 25 year analysis period. Had the 50 year projected service life of the concrete shallow trench been used as the analysis period, the direct burial would have required replacement at the 25 year point or been allowed to generate significant repair costs. Sensitivity analysis on this changed parameter would have shown a dramatic change in the results.

If however, the period of ownership was expected to be 25 years or less, then the direct burial would have been the probable choice unless other factors influenced the decision.

While the pavement analysis portion of the study does not address historical ownership cost items, it does offer a potentially useful model on how principles of life-cycle cost analysis can be implemented to control the cost of ownership for other infrastructure systems. Researchers in this area are attempting to implement the evolution of pavement management systems into larger integrated "total facilities management" systems useful for ownership control on all types of infrastructure systems (Building Research Board 1991).



## CHAPTER VI      CONTROLLING THE COST OF OWNERSHIP

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### 6.1 OBSTACLES TO LIFE-CYCLE COSTING

"The idea that life-cycle costs can be controlled has wide appeal, but life-cycle cost analysis has not been consistently applied in the design and management of buildings."  
(Building Research Board 1991)

A general attitude in both the public and private sectors that life-cycle costing is too difficult, time consuming, and not based on reliable data, is an attitude that generates a major obstacle to implementation of life-cycle costing principles. These concerns are somewhat valid and quite common throughout the construction industry but can be overcome with further education and proven performance of life-cycle costing application.

Presenting another major obstacle to life-cycle costing, is a method of capital budgeting which reduces acquisition costs in order to reduce the initial investment at the expense of proper funding for construction of individual projects. By squeezing projects into the budget at the expense of adequate funding levels, cuts are mandated in construction costs to meet the budgetary restrictions. Because the correlation of construction to future maintenance and repair costs is poorly documented and even more difficult to quantify, it is hard to favorably argue for a higher investment at acquisition as a method to reduce future maintenance

and repair outlays. Firms using this type of budgeting policy have failed to realize the impact on the annual operating budget brought about by increased ownership costs that could have been eliminated or minimized through the application of life-cycle costing.

Yet another serious obstacle was identified by the Committee on setting Federal Construction Standards to Control Building Life-Cycle Costs is the lack of accepted industry standards for describing operational performance of all building components.

The Committee noted:

"There is relatively little feedback of information from buildings in service to new designs, which might yield a reliable basis for estimating how maintenance efforts influences service life of buildings."

Such feedback could assist in documenting the validity of life-cycle costing as a necessary management tool and provide the foundation to one of the nation's most sensitive infrastructure issues.

## 6.2 LIFE-CYCLE COSTING AS A BASIC POLICY

Repairing, upgrading, and expanding America's deteriorating infrastructure will require quadrupling the current investment by the year 2000 (Gole 1988). Life-cycle costing must become a matter of basic policy for public as well as private investment decisions in order to optimize use of societies declining resources and meet these future obligations.

Without understanding the need for such a basic policy, infrastructure related decisions will continue to be made such that financial liabilities are unnecessarily increased. Consequently, the future liabilities will not be met and precipitate the deferral of necessary maintenance and repair items thereby compounding the affects of an already poor management decision.

One must realize the importance of planning for the future. Life-cycle costing as a basic policy provides the capability to construct and maintain infrastructure systems in the most cost effective manner given the established requirements.

### 6.3 LIFE-CYCLE COST DATA BASES

Chapter IV discussed the current sources of data for use in life-cycle cost forecasting. This section addresses the use of data bases for development of historical records to track the various ownership costs over the life of a particular system. Specifically, the cost of operations, maintenance, and repair.

As previously discussed, the lack of available historical information on maintenance and repair items makes it difficult to justify the need for higher initial investments at acquisition in order to reduce future recurring costs in the areas of maintenance and repair. Through development of data bases on a cost accounting structure, all incurred maintenance and repair costs could be better associated with specific ownership items.

Through development of Management Information Systems (MIS), in combination with an adequately funded maintenance and repair program, historical record keeping of ownership costs for a specific infrastructure system could assist with better correlating the initial construction activities to the incurred maintenance and repair items. This information could assist in providing feedback for planning and design of future systems, and more importantly provide a mechanism to lend credibility to the application of life-cycle costing policies and procedures.

#### 6.4 MANAGEMENT ACCOUNTABILITY

As a decision maker and custodian of infrastructure related issues, one has the responsibility to insure every dollar invested in infrastructure purchases the best system that achieves the required results at the lowest cost of ownership.

Life-cycle costing is a method by which the decision maker may select, implement, and defend as necessary the basis for one's decision. However, some view this method of analysis as one that will keep one from getting the project one really wants (Marshall 1987). Under pressure from both external and internal sources, one may be forced to manipulate the figures to obtain the desired results. As discussed by Senator Robert Morgan, Chairman, Senate Subcommittee on Buildings and Grounds (Dell'Isola and Kirk 1983),

"I am disturbed when a consulting engineer tells me and my committee he can make his life-cycle cost estimate come out any way he wants"

All levels of management must understand the need for life-cycle costing and accept the results. This is not to say one should not question the parameters used in the analysis, but rather be willing to understand and accept as necessary the principles involved in life-cycle costing as a basis for the results. One must be prepared to adequately convince those that question the results on the long lasting consequences and importance of ownership costs in infrastructure related decisions, specifically, the commitment to future maintenance and repair levels.

## CHAPTER VII      CONCLUSION

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### 7.1 SUMMARY

With increased emphasis on total life-cycle costing, more evaluation using costs associated with the complete life of an infrastructure system will take precedence over selecting a system based solely on initial acquisition costs. The major challenge for the future is to develop a heightened degree of cost consciousness in both planning and design of new infrastructure systems. Life-cycle costs must be considered a major design parameter with an emphasis applied to cost on a total life-cycle basis. With life-cycle costing as a basic policy, the following items should become a matter of routine:

- o Cost growth for infrastructure systems will decrease
- o Estimates will improve with respect to accuracy
- o Data bases and data collection will improve
- o Budgeting procedures will improve with better data
- o Future costs can be better projected and funded

In summary, greater cost visibility is required for all infrastructure systems which in turn will yield improved use of all resources and insure every dollar invested purchases the best infrastructure system to achieve the specified results at the lowest cost of ownership.

## 7.2 RESEARCH OBJECTIVES FULFILLMENT

Through this study a better understanding of infrastructure economics, as it relates to the total cost of ownership for infrastructure systems, has been developed. This study offered a basic understanding of the parameters involved with life-cycle costing to provide an introduction to a methodology by which the most cost effective infrastructure system may be selected with an emphasis on the economic consequences of each alternative system considered.

Through the analysis of the data collected for the infrastructure systems discussed, the study identified strengths and weaknesses of the decision to select these specific types of systems and offered various feedback mechanisms that may assist with planning and design of similar future systems. Even though complete correlation of historical costs could not be accomplished due to insufficient historical data, an understanding of the basis for the analysis will contribute to future related work in this important area.

### 7.3 RECOMMENDATIONS FOR FUTURE WORK

This research study offers significant opportunity for further related work in the area of data base development for historical record keeping of maintenance and repair cost items. With more complete and accurate data one can better discuss the impacts of the initial decisions made during design and construction as they pertain to the actual maintenance and repair costs incurred over the service life of an infrastructure system in order to provide a feedback mechanism for future designs.

Additionally, little material exists as a training media in this vital infrastructure related area, nor do any higher educational systems offer related classroom opportunities in life-cycle costing. This study in addition to some of the reference texts and the CERL data base could provide a foundation for a course syllabus to be possibly the first of its kind at the university level. What better place to instill the value of economic consequences in decision making for infrastructure investments than at the root of the construction industry in the nation's universities.



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APPENDIX A  
CAPITAL ASSET PRICING MODEL  
(SOURCE: BREALY AND MYERS 1988)

## PRELI ESTIMATING CASE STUDY

### ESTIMATING THE COST OF CAPITAL

1. Using the Beta as calculated below and the Capital Asset pricing Model, the most likely discount rate or cost of capital for Preli was calculated based on the associated risk for this capital budgeting decision.

2. Capital Asset Pricing Model:  $K_e = R_f + \text{Beta asset} (K_m - R_f)$

where:  $K_e$  = cost of firms equity or discount rate

$K_m$  = expected return on the market =  $R_f$  + market risk premium

$R_f$  = risk free rate (6 month T-bill rate)

Beta = level of systematic risk associated with the company

3. Since it was given that the firm had no outstanding debt, we can assume it is all equity financed. Therefore, the Beta of asset and Beta of equity are equal for a 100% equity financed firm. Since the true business risk of a firm is reflected in the risk of it's assets, it is the asset Beta that should be used in the Capital Asset Pricing Model to determine the firms cost of capital.  $B_{asset} = B_{equity}$  for this analysis (Principles of Corporate Finance, Brealey and Myers, 1988).

4. The risk free rate,  $R_f$ , as of 4 March, 1991 was 6.06% for a 6 month T-bill and was taken from CNN Headline News of the same date.

5. The market risk premium over the past sixty years was taken from The Principles of Corporate Finance at 8.4%.

6. The appropriate Beta for Preli will be determined by averaging ten similar construction firms Beta values as obtained from The Value Line Investment survey of 2 Feb, 1991.

	<u>COMPANY</u>	<u>Beta</u>
1.	BLOUNT, INC.	.85
2.	CBI INDUSTRIES	1.00
3.	CONTEX, CORP	1.20
4.	DRAVO, CORP	1.30
5.	FLUOR, CORP	1.45
6.	FOSTER WHEELER	1.30
7.	MORRISON KNUDSON	1.10
8.	PERRINI, CORP	.90
9.	STONE AND WEBSTER	.90
10.	TOLLBROTHERS	<u>1.25</u>
	TOTAL	11.25

Average Beta = Total Beta / 10 =  $11.25/10 = 1.125$

7.  $K_e = R_f + \text{Beta asset} (K_m - R_f) = 6.06\% + 1.125(8.4\%) = 15.51\%$

APPENDIX B

LIFE-CYCLE COST ESTIMATING FORMS

(SOURCE: DELL'ISOLA AND KIRK 1983)

## Life Cycle Cost Model

Annualized Cost		X PWA =	Total Cost P W		Project	Floors	LC Period	Date
					Location	GSF	% Disc. Rate	Phase
					Bldg. Type	NSF	PP	Legend
					Const. Type	Cost Units	PWA	Target Actual/Est.
Financing Costs			Functional Use Costs		Denial Of Use Costs			Depreciation
								Salvage Value
Initial Costs			Operation Costs		Maintenance Costs		Alteration Costs	Replacement Costs
								Associated Costs
Structural	Initial Cost X PP							
Architectural								
Mechanical								
Electrical								
Equipment								
Site								
Other								

PP - Periodic Payment to pay off loan of \$1 00  
PWA - Present Worth of Annuity

FIGURE A-12  
Life cycle cost model

# Data Required for Life Cycle Cost Estimating

					Design Quantities			
					Original	Alternative 1	Alternative 2	Alternative 3
Variable	Type	Symbol	Nomenclature	Units Of Measure	Reference			
Economic	AA		Building Economic Life	Years				
	AB		Project Discount Rate	% Of Cost				
	AC		Escalation Rate Yr - Labor & Materials	% Of Cost				
	AD		Escalation Rate Yr - Heating Fuel	% Of Cost				
	AE		Escalation Rate Yr - Cooling Fuel	% Of Cost				
	AF		Escalation Rate Yr - Lighting Fuel	% Of Cost				
	AG		Escalation Rate Yr - Domestic Hot Water Fuel	% Of Cost				
	AH		Escalation Rate Yr - Maintenance	% Of Cost				
	AI		Escalation Rate Yr - Associated Costs	% Of Cost				
Facility	BA		Gross Area Of Building	Sq Ft	Sketch			
	BB		Normal Building Population	Each	Project			
	BC		Required Lighting Year	Hours	Project			
	BD		Average Amount Of Lighting Power Required Over Floor Area	Watt Sq Ft				
	BE		Domestic Hot Water Boiler Energy Required Gallon Heated	BTU Gal	Manuf			
	BF		Domestic Hot Water Usage Year	Days	Project			
	BG		Daily Hot Water Gallons Person	Gallon				
	BH		Estimated Hourly Heating Load	BTU HR	ASHRAE			
	BI		Estimated Hourly Cooling Load	BTU HR	ASHRAE			
	BJ		Air Conditioning Power Per Design Ton	KW				
Site & Climatic	CA		Area Design Cost Factor	N A				
	CB		Fuel Costs - Heating	\$/Million BTU				
	CC		Fuel Costs - Cooling	\$/KWh				
	CD		Fuel Costs - Domestic Hot Water	\$/Million BTU				
	CE		Fuel Costs - Lighting	\$/KWh				
	CF		Equip Full Load Hrs	Hr				
	CG		A C Equip Per Year	Day °F				
	CH		Heating Degree Days					
	CI		Summer Inside Design Temperature	°F				
	CJ		Winter Inside Design Temperature	°F				
	CK		Summer Outside Design Temperature	°F				
			Winter Outside Design Temperature	°F				

FIGURE A-13  
Data required for life cycle cost estimating.



**Structural Life Cycle Costing**  
(Foundations, Substructure, Superstructure)

		Original		Alternative 1		Alternative 2		Alternative 3	
		Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth
Initial Costs	Element								
	01 Foundations								
	011 Standard Foundations								
	012 Special Foundations								
	02 Substructure								
	021 Slab On Grade								
	022 Basement Excavation								
	023 Basement Walls								
	03 Superstructure								
	031 Floor Construction								
Maintenance Costs	032 Roof Construction								
	033 Stair Construction								
	Total Initial Cost								
	Annual Costs @ ____ % Discount Rate								
	Escal. Rate ____ % PWA (With Escal.) Factor								
	01 Foundations								
	A Inspection								
	B Routine Repair, Moistureproofing, Resealing								
	C								
	02 Substructure								
Replacement Costs	A Inspection								
	B Routine Repair, Moistureproofing, Resealing								
	C Painting, Touch up, Routine Refinishing								
	D								
	03 Superstructure								
	A Inspection								
	B Cleaning & Sweeping Of Firs. Strs. (If No Arch. Fin.)								
	C Painting, Touch up, Routine Refinishing								
	D								
	Total Annual Maintenance Costs								
Associated Costs	Single Expenditures @ ____ % Discount Rate								
	Item Replaced	Year	PW Factor						
	A								
	B								
	C								
	D								
	Total Replacement Costs								
	Annual Costs @ ____ % Discount Rate								
	Escal. Rate ____ % PWA (With Escal.) Factor								
	A								
Salvage Value	B								
	C								
	Total Annual Associated Costs								
	Final Value @ ____ Year PW Factor								
	01 Foundations								
	02 Substructure								
	03 Superstructure								
	Total Salvage Value								
	LCC								
	Total Present Worth Costs								

PW - Present Worth      PWA - Present Worth Of Annuity

**FIGURE A-14**  
Structural life cycle costing for foundations, substructure, and superstructure

**Architectural Life Cycle Costing Estimate**  
Part I (Exterior Closure, Roofing)

		Original		Alternative 1		Alternative 2		Alternative 3	
		Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth
Initial Costs	Element								
	04 Exterior Closure								
	041 Exterior Walls								
	042 Exterior Doors And Windows								
	05 Roofing								
	0501 Roof Coverings								
	0502 Traffic Toppings & Paving Membranes								
	0503 Roof Insulation & Fill								
	0504 Flashings & Trim								
	0505 Roof Openings								
	Total Initial Cost								
Maintenance Costs	Annual Costs @ ____% Discount Rate								
	Escal. Rate ____% PWA (With Escal.) Factor ____								
	04 Exterior Closure								
	A Cleaning Windows, Spandrels								
	B Routine Erection Of Screens, Awnings								
	C Touch Up, Resealing, Routine Refinishing								
	D Routine Replacement Of Glazing, Panels								
	E								
	05 Roof								
	A Inspection								
	B Routine Maintenance Of Roof Surface								
	C Cleaning Gutters, Drains								
	D Resealing, Skylight Repairs								
	E Parapet Repointing								
	F								
	Total Annual Maintenance Costs								
Replacement Costs	Single Expenditures @ ____% Discount Rate								
	Item Replaced	Year	PW Factor						
	A Exterior Restoration								
	B Exterior Painting								
	C Roof Covering								
	D Painting, Reflashing								
	E								
	F								
	Total Replacement Costs								
Associated Costs	Annual Costs @ ____% Discount Rate								
	Escal. Rate ____% PWA (With Escal.) Factor ____								
	A								
	B								
	C								
	Total Annual Associated Costs								
LCC Salvage Value	Final Value @ ____Year PW Factor ____								
	04 Exterior Closure								
	05 Roof								
	Total Salvage Value								
Total Present Worth Costs									

PW — Present Worth      PWA — Present Worth Of Annuity

**FIGURE A-15**

Architectural life cycle costing estimate—part 1, for exterior closure and roofing.

**Architectural Life Cycle Costing Estimate**  
Part II (Interior Construction, Conveying Systems)

		Original		Alternative 1		Alternative 2		Alternative 3	
		Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth
Initial Costs	Element								
	06 Interior Construction								
	061 Partitions								
	062 Interior Finishes								
	063 Specialties								
Initial Costs	07 Conveying Systems								
	0701 Elevators								
	0702 Moving Stair & Walks								
	0703 Dumbwaiters								
	0704 Pneumatic Tube Systems								
Initial Costs	Total Initial Cost								
Operation Costs	Annual Costs @ ____ % Discount Rate								
	Escal. Rate ____ % PWA (With Escal.) Factor ____								
	A Salaries (Operation, Etc.)								
	B Elevator Energy Cost								
	C Moving Stairs & Walks Energy Cost								
	D Dumbwaiter Energy Cost								
	E Pneumatic Tube System Energy Cost								
	F								
	G								
	Operation Costs	Total Annual Operation Costs							
Maintenance Costs	Annual Costs @ ____ % Discount Rate								
	Escal. Rate ____ % PWA (With Escal.) Factor ____								
	06 Interior Construction								
	A Cleaning & Dusting Partitions, Chalkboards								
	B Maintenance Of Operable Partitions								
	C Carpet Cleaning, Sweeping								
	D Tile, etc. Floor Cleaning & Sweeping								
	E Stair Cleaning (If No Arch. Finish, Use Struct. Form Plan)								
	F								
	07 Conveying Systems								
Maintenance Costs	A Preventative Maintenance, Inspection								
	B Routine Cleaning								
	C Repair, Adjustment								
	D								
	E								
Maintenance Costs	Total Annual Maintenance Costs								
Replacement Costs	Single Expenditures @ ____ % Discount Rate								
	Item Replaced Year PW Factor								
	A Motors, Lifts								
	B								
	C								
Replacement Costs	Total Replacement Costs								
Associated Costs	Annual Costs @ ____ % Discount Rate								
	Escal. Rate ____ % PWA (With Escal.) Factor ____								
	A								
Associated Costs	B								
	C								
Associated Costs	Total Annual Associated Costs								
Salvage Value	Final Value @ ____ Year PW Factor ____								
	06 Interior Construction								
	07 Conveying Systems								
Salvage Value	Total Salvage Value								
	LCC	Total Present Worth Costs							

PW = Present Worth PWA = Present Worth Of Annuity

**FIGURE A-16**  
Architectural life cycle costing estimate—part 2, for interior construction and conveying systems

# **Mechanical Life Cycle Costing Estimate**

		Original		Alternative 1		Alternative 2		Alternative 3	
		Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth
Initial Costs	Element								
	08 Mechanical Systems								
	081 Plumbing								
	082 Heating, Ventilation, & Air Conditioning								
	083 Fire Protection								
	084 Special Mechanical Systems								
	Total Initial Cost								
Operation Costs	Annual Costs @ ____% Discount Rate								
	Escal. Rate ____% PWA (With Escal.) Factor								
	A Salaries (Operation, Etc.)								
	B Domestic Hot Water Energy Cost								
	C Heating Energy Cost								
	D Ventilation Energy Cost								
	E Air Conditioning Energy Cost								
	F Pumps, Motors, Etc. Energy Cost								
	G Fire Protection Energy Cost								
	H								
	Total Annual Operation Costs								
Maintenance Costs	Annual Costs @ ____% Discount Rate								
	Escal. Rate ____% PWA (With Escal.) Factor								
	08 Mechanical Systems								
	A Plumbing & Sewage Cleanout, Repair								
	B Domestic H.W. System Repair, Adjust								
	C HVAC Preventative Inspection, Testing								
	D Routine Cleaning Ducts, Plenums								
	E Routine Cleaning Boilers, Controls								
	F Repair Heating System								
	G Repair Ventilation System								
	H Repair Air Conditioning System								
	I Adjust Controls & Instrumentation								
	J Routine Replace Filters, Insulation								
	K HVAC System Balancing								
	L Fire Protection System Cleaning								
	M Fire Protection System Repair								
		Total Annual Maintenance Costs							
Replacement Costs	Single Expenditures @ ____% Discount Rate								
	Item Replaced      Year      PW Factor								
	A H.W. Boiler								
	B Pumps, Motors								
	C Control System								
	D								
	E								
	Total Replacement Costs								
Associated Costs	Annual Costs @ ____% Discount Rate								
	Escal. Rate ____% PWA (With Escal.) Factor								
	A								
	B								
	Total Annual Associated Costs								
Salvage Value	Final Value @ ____ Year      PW Factor								
	08 Mechanical System								
	Total Salvage Value								
LCC	Total Present Worth Costs								

PW — Present Worth      PWA — Present Worth Of Annuity

**FIGURE A-17**  
Mechanical life cycle costing estimate.

# Electrical Life Cycle Costing Estimate

		Original		Alternative 1		Alternative 2		Alternative 3	
		Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth
Initial Costs	Element								
	09 Electrical								
	091 Service & Distribution								
	092 Lighting & Power								
	093 Special Electrical System								
Initial Costs	Total Initial Cost								
Operation Costs	Annual Costs @ ____ % Discount Rate								
	Escal Rate ____ % PWA (With Escal ) Factor ____								
	A	Salaries (Operation, Etc )							
	B	Lighting Energy Cost							
	C	Communications Alarm Energy Cost							
	D	Emergency Light Power Energy Cost							
	E	Electric Heating Energy Cost							
	F								
Operation Costs	Total Annual Operation Costs								
Maintenance Costs	Annual Costs @ ____ % Discount Rate								
	Escal Rate ____ % PWA (With Escal ) Factor ____								
	A	Inspection, Testing, & Maint Of Safety							
	B	Relamping And Routine Replacement							
	C	Repair Communications Alarm System							
	D	Repair Electric Heating System							
	E								
Maintenance Costs	Total Annual Maintenance Costs								
Replacement Costs	Single Expenditures @ ____ % Discount Rate								
	Item Replaced	Year	PW Factor						
	A	Distribution System							
	B	Lighting System							
	C	Commun Alarm							
	D	Emergency Generator							
	E	Elec Heat Equip							
	F								
	G								
Replacement Costs	Total Replacement Costs								
Associated Costs	Annual Costs @ ____ % Discount Rate								
	Escal Rate ____ % PWA (With Escal ) Factor ____								
	A								
Associated Costs	Total Annual Associated Costs								
Salvage Value	Final Value @ ____ Year PW Factor ____								
	09 Electrical								
Salvage Value	Total Salvage Value								
LCC	Total Present Worth Costs								

PW - Present Worth      PWA - Present Worth Of Annuity

FIGURE A-18

Electrical life cycle costing estimate.

# Equipment Life Cycle Costing Estimate

		Original		Alternative 1		Alternative 2		Alternative 3	
		Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth
Initial Costs	Element								
	11 Equipment								
	111 Fixed And Movable Equipment								
	112 Furnishings								
	113 Special Construction								
	Total Initial Cost								
Operation Costs	Annual Costs @ ____ % Discount Rate								
	Escal. Rate ____ % PWA (With Escal.) Factor								
	A Salaries (Operation, Etc.)								
	B Food Service Equip. Energy Cost								
	C Vending Equip. Energy Cost								
	D Waste Handling Equip. Energy Cost								
	E								
	F								
	G								
	Total Annual Operation Costs								
Maintenance Costs	Annual Costs @ ____ % Discount Rate								
	Escal. R: ____ % PWA (With Escal.) Factor								
	A Inspection And Testing Of Equipment								
	B General Cleaning, Dusting Of Equip.								
	C Repair Food Service Equipment								
	D Repair Vending Equipment								
	E Repair Waste Handling Equipment								
	F								
	G								
	Total Annual Maintenance Costs								
Replacement Costs	Single Expenditures @ ____ % Discount Rate								
	Item Replaced	Year	PW Factor						
	A								
	B								
	C								
	Total Replacement Costs								
Associated Costs	Annual Costs @ ____ % Discount Rate								
	Escal. Rate ____ % PWA (With Escal.) Factor								
	A								
	B								
	Total Annual Associated Costs								
Salvage Value	Final Value @ ____ Year PW Factor								
	11 Equipment								
	Total Salvage Value								
LCC	Total Present Worth Costs								

PW - Present Worth PWA - Present Worth Of Annuity

**FIGURE A-19**  
Equipment life cycle costing estimate

# Site Work Life Cycle Costing Estimate

		Original		Alternative 1		Alternative 2		Alternative 3	
		Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth
Initial Costs	Element								
	12 Sitework								
	121 Site Preparation								
	122 Site Improvements								
	123 Site Utilities								
	124 Off Site Work								
	Real Estate								
Total Initial Cost									
Operation Costs	Annual Costs @ ____% Discount Rate								
	Escal. Rate ____% PWA (With Escal.) Factor ____								
	A Salaries (Operation, Etc.)								
	B Lighting Energy Cost								
	C Snow Melting System Energy Cost								
	D								
	E								
Total Annual Operation Costs									
Maintenance Costs	Annual Costs @ ____% Discount Rate								
	Escal. Rate ____% PWA (With Escal.) Factor ____								
	A General Site Cleaning								
	B Landscaping Maintenance								
	C Snow & Ice Removal (Parking, Walks)								
	D Relamping And Routine Replacement								
	E								
Total Annual Maintenance Costs									
Replacement Costs	Single Expenditures @ ____% Discount Rate								
	Item Replaced Year PW Factor								
	A Trees, Shrubs								
	B Parking Pavement								
	C								
	D								
	E								
Total Replacement Costs									
Associated Costs	Annual Costs @ ____% Discount Rate								
	Escal. Rate ____% PWA (With Escal.) Factor ____								
	A								
	B								
	C								
	D								
	Total Annual Associated Costs								
Salvage Value	Final Value @ ____ Year PW Factor ____								
	12 Sitework								
	Total Salvage Value								
LCC Total Present Worth Costs									

PW - Present Worth PWA - Present Worth Of Annuity

**FIGURE A-20**  
Site work life cycle costing estimate

# Life Cycle Cost Estimate Summary

		Original		Alternative 1		Alternative 2		Alternative 3	
		Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth	Estimated Costs	Present Worth
Initial Costs	Initial Costs								
	Planning Design, Special Studies Fees _____								
	Structural _____								
	Architectural (Parts I & II) _____								
	Mechanical _____								
	Electrical _____								
	General Conditions & Profit ____% (If Approp.) _____								
	Equipment _____								
	Sitework _____								
	Other _____								
	Contingencies ____% _____								
	Escalation ____% _____								
	Total Initial Cost								
	Operations								
	Architectural (Part II) _____								
	Mechanical _____								
	Electrical _____								
	Equipment _____								
	Sitework _____								
	Other _____								
	Total Annual Operations Costs								
Owning Costs	Maintenance								
	Structural _____								
	Architectural (Parts I & II) _____								
	Mechanical _____								
	Electrical _____								
	Equipment _____								
	Sitework _____								
	Other _____								
	Total Annual Maintenance Costs								
	Alterations								
	(Items) Altered                      Year      PW Factor								
	A _____								
	B _____								
	C _____								
	D _____								
	Total Alteration Costs								
Salvage Value	Replacement								
	Structural _____								
	Architectural (Parts I & II) _____								
	Mechanical _____								
	Electrical _____								
	Equipment _____								
	Sitework _____								
	Other _____								
	Total Replacement Costs								
	Financing Costs								
	Functional Use Costs								
	Denial Of Use Costs								
	Associated								
	A _____								
	B _____								
	C _____								
	D _____								
	E _____								
LCC	Total Annual Associated Costs								
	Total Owning Present Worth Costs								
	Salvage								
	Building (Struc. Arch. Mech. Elec. Equip.) _____								
	Other _____								
LCC	Sitework _____								
	Total Salvage Value								
LCC	Total Present Worth Life Cycle Costs								
	Life Cycle Present Worth Dollar Savings								

FIGURE A-21  
Life cycle costing estimate summary.



APPENDIX C  
SOURCES OF DATA FOR COST DEVELOPMENT  
(SOURCE: RIVERSO 1984)

### 7.3 Source of Data

One of the three inputs into the Life Cycle Costing system, owner's profile, has already been discussed. The other two sources of input, which provide the necessary information for the computation of the life cycle cost estimate, are in the form of databases and procedural references. In order to fully expand on these sources of input, each of the life cycle cost's possible sources will be discussed.

LCC-1 Initial Construction Costs: Lump sum initial construction cost data may be obtained from contractors' historical cost files, cost manuals, and supplier's quotes. These data sources have been utilized by the Construction Industry for many decades, and are readily available. In order to be compatible with the proposed Life Cycle Cost system, the data files, which for the most part are organized in accordance with the Masterformat, need to be re-organized in accordance with the Unifformat. This will provide detailed data along a systems format, which is

more compatible with the proposed life cycle cost model.

LCC-2 User Function Costs: These costs are unique for each project, and require development, as opposed to a collective database. A great deal of information about the operations and productivity of the operations needs to be collected, in order to properly attribute costs and/or benefits with alternative construction designs and methods.

LCC-3 Maintenance and LCC-4 Custodial Costs: These are annual recurring costs, which require data arranged in a formal database. These costs are dependent on quality of both initial construction, and on the commitment to upkeep. Specific requirements of the database are presented latter.

LCC-5 Energy and Utility Costs: These are annual recurring costs which depend on the accuracy of two sets of items. The first set involves the prediction of the energy demand. These predictions are based on principles promulgated by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the Illumination Engineers Society (IES). The computations involved in these predictions are

becoming more accurate and less time consuming with the advent of computerized systems, such as the Building Loads Analysis and Systems Thermodynamics (BLAST) program developed by the Army Corps of Engineers Research Laboratory and the DOE-II program developed by the Department of Energy. The second set of items involves the prediction of inflation and escalation rates for future energy prices. It should suffice to say that in a world in which our main source of energy is controlled by unstable countries, and more knowledge of new energy sources is being discovered daily, that the validity and applicability of these predictions are questionable. Even so, this is the only means of preparing future estimates for costs of this category. Each building system will be associated with its energy load. To properly estimate energy usage, the alternative may require an interdependent relationship with another system. For example, the exterior closure system, Unifomat division 4, accounts for heat losses and gains through the walls, and solar heat gains through the fenestration. The cost of the energy loads will be dependent upon the mechanical system employed.

LCC-6 Administrative Costs: These costs are unique for each individual project, and require development, as opposed to a collective database. Real estate taxes are dependent on the percent dollar assessment valuation and the tax rate of the local level of government. Insurance is dependent on the ratings of the local police and fire departments, and the location of the project. These and other administrative costs require individual analysis for each project.

LCC-7 Alteration Costs: Future scheduled and planned alterations may be estimated based on initial construction cost estimates. Therefore, the same database utilized to estimate initial construction costs, may be employed to estimate these costs.

LCC-8 Replacement Costs: A database is required in order to determine the scheduled and required replacement for different systems within the building project. These costs also need to be prorated for quality of initial construction and quality of preventive maintenance and upkeep.

LCC-9 Salvage Value: This is a future lump sum price, which is a function of many different items. As pointed out earlier, the growth in the rate of

1 2

awareness and concern prospective owners are expressing in life cycle costs has created a need for expert assessment of the salvage value. Salvage value is a benefit and/or cost which is derived from the quality of construction, level of maintenance, location, inflation, and supply and demand principles. Two salvage values exist: the salvage values of individual systems once replaced, or at the period in time when the owner disposes of the building. However, to estimate the salvage value of each individual system when an owner decides to sell a building, ignores three items. First, the value of the summation of all the building components together is greater than the sum of the individual building systems' values. This phenomenon is labeled as the effects of synergism. Second, the value of a building in some locations increases at a rate higher than the rate of inflation. This results from market phenomena. Third, prospective buyers are not always willing to pay more for a building simply because its life cycle costs promises to be lower. These three items should be conservatively estimated and accounted for.

LCC-10 Other Costs: These costs are developed and estimated for each individual project, and therefore require no database.

According to the discussion presented above, pertaining to the source of life cycle cost data, only LCC-1,3,4,7, and 8 require information which is best organized by the use of a database. These life cycle costs are as follows:

LCC-1 Initial Construction Costs

LCC-3 Maintenance Costs

LCC-4 Custodial Costs

LCC-7 Alteration Costs

LCC-8 Replacement Costs

The databases required for LCC-1 and LCC-7 are readily available. However, there are few databases in existence for LCC-3, LCC-4, and LCC-8, as discussed below.

#### 7.4 Current Databases Available

The proposed Life Cycle Cost system operates within the same GIGO principles as a computer program does. The GIGO rule states that if garbage is fed into the system, the system shall return garbage out. Stated differently, the results the Life Cycle Cost system yields are dependent upon

the input fed into it. As initial construction cost data, which is utilized in developing estimates for both initial construction (LCC-1) and alteration (LCC-7) costs, is readily available, the following discussion pertains to maintenance (LCC-3), custodial (LCC-4), and replacement (LCC-8) costs. Previous methods of estimating these costs were dependent on estimating them as a percentage of original costs. Although these three life cycle costs may be developed for each project individually, a database would provide more accurate, more consistent, and less time consuming results. Currently two databases have been developed which are available to Life Cycle Cost system users.

The first database, which is described as an 'industry first attempt', was developed by Alphonse Dell'Isola and Stephen Kirk. Their book, 'Life Cycle Cost Data', was published in 1983, and provides data on annual maintenance costs, replacement lives, and the cost of replacement as a percentage of original cost. [81] Maintenance costs, as they define them, include custodial, repair, contract maintenance, and maintenance staff costs. The combination of custodial and maintenance costs presents no problem of compatibility with the proposed Life Cycle Cost system. In fact, without considering the quality of Dell'Isola's and Kirk's data, their database satisfies the requirements of the database needed to complete the input for the proposed system. Data is organized and classified in terms of the Uniformat.



The format for presenting this information is shown in Figure 7.8. [82] This database compiles information from more

Item description	Unit of measure	Maintenance description	Maintenance annual cost, \$			Energy demand (EU)	Replacement life, yrs	4. Replaced
			Labor	Material	Equipment			
Used to document UNIFORMAT category and describe specific facility items analyzed.	Given for each task	Used to describe specific maintenance tasks and corresponding labor performance standard(s)	1	2	3	4	5	6
			1 Used to convert labor hours into annual costs 2 Used to convert material requirements into annual costs 3 Used to convert maintenance equipment into annual costs 4 Used to record energy consumption requirements for the facility items 5 Used to document replacement life of significant components of facility items 6 Used to estimate percent of facility item cost replaced at the year specified (see Replacement life)					

Figure 7.8 Dell'Isola's and Kirk's LCC Database\*

\* Reprinted from 'Life Cycle Cost Data'.

than 24 different sources of data, as shown in Figure 7.9. [83]

The second database has been, and is presently, being developed by the Army Corps of Engineers Construction Engineering Laboratory. Research concludes that data collection of maintenance and repair costs for army installations is not feasible at this time. This is because records of the army's buildings and their characteristics lack the necessary detail to develop a complete life cycle cost database. Therefore, the research concludes that a life cycle cost database is best developed by Engineered Performance Standards (EPS). The following is a general outline of the steps utilized by the Engineered Performance Standards method to develop maintenance and repair data for building components [84]:

APPENDIX D

DELL'ISOLA AND KIRK DATA

(SOURCE: DELL'ISOLA AND KIRK 1983)

**TABLE E-1**  
**LIFE CYCLE DATA**

ITEM DESCRIPTION	UNIT OF MEASURE	MAINTENANCE DESCRIPTION	MAINTENANCE ANNUAL COST			ENERGY DEMAND (EU)	REPLACE MENT LIFE (YRS)	PERCENT REPLACED
			LABOR	MATERIAL	EQUIPMENT			
04 EXTERIOR CLOSURE 041 EXTERIOR WALLS 0411 EXTERIOR WALL CONSTRUCTION								
Masonry Veneer; 4" brick & 4" block, insulation & vapor barrier	WSF	Repointing joints (4.0 min. every 15 years)	.06	.02	.001	N/A	75	100
Aluminum Panel; insulation & vapor barrier	WSF	Minor repair, cleaning (2.0 min. every 6 years)	.08	.01	.001	N/A	50	100
Metal Panel; insulation & vapor barrier	WSF	Minor repair, cleaning (2.0 min. every 6 years)	.08	.01	.001	N/A	40	100
04 EXTERIOR CLOSURE 042 EXTERIOR DOORS & WINDOWS 0421 WINDOWS								
Fixed glazing frame, hardware	WSF	Lobby, storefront; Wash and Squeegee dry both sides of glass. (.18 min./week)	1.87	2.0	.04	N/A	40	100
	WSF	Office, other areas: (.18 min./quarter)	.14	.02	.01			
	WSF	Repair glazing, frame & hardware	.01	.01	.001			

ITEM DESCRIPTION	UNIT OF MEASURE	MAINTENANCE DESCRIPTION	MAINTENANCE ANNUAL COST			ENERGY DEMAND (EU)	REPLACE MENT LIFE (YRS)	PERCENT REPLACED
			LABOR	MATERIAL	EQUIPMENT			
04 EXTERIOR CLOSURE 042 EXTERIOR DOORS & WINDOWS 0423 EXTERIOR DOORS								
Hollow metal door, frame, hardware	WSF	Damp clean both sides (.12 min/quarter)	.08	.01	.01	N/A	40	100
	WSF	Repair door, frame, hardware	.10	.05	.02			
Solid Core Wood Door	WSF	Damp clean both sides (.12 min/quarter)	.08	.01	.01	N/A	40	100
	WSF	Repair door, frame, hardware	.12	.06	.02			
	WSF	Paint, 2 coats every 4 years	.07	.02	.02			
05 ROOFING 0501 ROOF COVERINGS								
Tar and gravel built-up Membrane roofing, 5 ply - 15# felt	RSP	Preventative inspection (.01 min. per year)	.001	N/A	N/A	N/A	20	100
	RSP	Minor repair (.02 min. per year)	.002	.001	N/A			
Prepared roll Roofing, 15# felt	RSP	Preventative inspection (.01 min. per year)	.001	N/A	N/A	N/A	12	100
	RSP	Minor repair (.03 min. per year)	.003	.002	N/A			

**TABLE E-1**  
(continued)

ITEM DESCRIPTION	UNIT OF MEASURE	MAINTENANCE DESCRIPTION	MAINTENANCE ANNUAL COST			ENERGY DEMAND (EUI)	REPLACE MENT LIFE (YRS)	PERCENT REPLACED
			LABOR	MATERIAL	EQUIPMENT			
06 INTERIOR CONSTRUCTION 061 PARTITIONS 0611 FIXED PARTITIONS								
Drywall Partitions, Metal or Wood Studs	WSF	Minor repair (1.0 min. every 10 years)	.03	.01	.001	N/A	35	100
06 INTERIOR CONSTRUCTION 061 PARTITIONS 0612 DEMOUNTABLE PARTITIONS								
Baked Enamel Steel Partitions, Demountable, Full or Bank Height	WSF	Damp clean both sides (.12 min. per quarter)	.08	.01	N/A	N/A	25	100
	WSF	Minor repair (1.0 min. every 10 years)	.02	.01	.001			
06 INTERIOR CONSTRUCTION 061 PARTITIONS 0616 INTERIOR DOORS AND FRAMES								
Hollow Metal Door and Frame, Hardware	WSF	Damp clean both sides (.12 min./quarter)	.08	.01	N/A	N/A	30	100
	WSF	Repair Door, Frame, Hardware	.08	.04	.01			
Hollow Core Wood Door with Metal Frame, Hardware	WSF	Damp clean both sides (.12 min./quarter)	.09	.01	N/A	N/A	20	100
	WSF	Repair Door, Frame, Hardware	.10	.05	.02			
	WSF	Painting - 2 coats (1.0 every 6 years)	.03	.01	.001			

ITEM DESCRIPTION	UNIT OF MEASURE	MAINTENANCE DESCRIPTION	MAINTENANCE ANNUAL COST			ENERGY DEMAND (EUI)	REPLACE MENT LIFE (YRS)	PERCENT REPLACED
			LABOR	MATERIAL	EQUIPMENT			
06 INTERIOR CONSTRUCTION 062 INTERIOR FINISHES 0621 WALL FINISHES								
Interior Paint on Masonry	WSF	High Use Areas: Paint - 2 Coats (1.0 min. every 2 years)	.13	.03	.02	N/A	(See Maint)	N/A
	WSF	Low Use Areas Paint - 2 coats (1.0 min. every 7 years)	.04	.01	.01	N/A	(See Maint)	N/A
Interior Paint on Drywall	WSF	Change of Color; Paint - 2 coats (1.0 min. every 7 years)	.13	.03	.02	N/A	(See Maint)	N/A
	WSF	Otherwise: Paint - 2 coats (1.0 min. every 7 years)	.04	.01	.01	N/A	(See Maint)	N/A
Ceramic Tile, Glazed with Organic Adhesive	WSF	High Use Areas: Damp Cleaning Daily (.06 min. per day)	2.6	.10	.02	N/A	25	100
	WSF	Minor Repair Yearly	.01	.01	.001			
	WSF	Low Use Areas: Minor Cleaning	.10	.02	N/A			
	WSF	Minor Repairs, yearly	.01	.01	N/A			

APPENDIX E  
CERL DATA BASE

(Source: Neely, Neathammer, and Stirn May 1991)



**US Army Corps  
of Engineers**

Construction Engineering  
Research Laboratory

USACERL TECHNICAL REPORT P-91/12  
May 1991

# Maintenance Resource Prediction in the Facility Life-Cycle Process

by

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Robert D. Neathammer

James R. Stirn

Estimates of maintenance resources are needed during all phases of the Army facility life-cycle: planning, design, operation/maintenance, and demolition.

In the past, estimates that involved maintenance resources have been inaccurate due to the lack of a comprehensive data base containing maintenance costs. To improve this accuracy, the U.S. Army Construction Engineering Research Laboratory (USACERL) has developed a series of maintenance resource data bases which can be used in economic analyses. In addition, models have been devised for prediction of outyear maintenance costs. Computer programs have been developed to automate the data bases and prediction models.

This report describes the research and development for this project. Separate USACERL reports present the data base contents, computer program descriptions, and user manuals.

## 2 RESEARCH PROGRESS AND REPORTS PUBLISHED

### Research Progress

The research was conducted over 7 years. Most of the tasks were performed in parallel with reviews by an Army-wide steering committee at major milestone points. Yearly presentations on the research progress were made at the annual Worldwide Real Property Management System (RPMS) conferences.

HQDA formed an Army-wide maintenance steering committee (users' group) to guide the research. This committee was composed of one voting representative from every Army office involved in planning and programming of maintenance resources. The four largest MACOMs were asked to participate in the steering committee; three of these became actively involved in the research. Ten installations also served on the steering committee: six in the United States--Forts Devens, Bragg, Wood, Sill, Harrison, and Ord, and four in Germany--Baumholder, Wuerzburg, Pirmasens, and Grafenwohr. The Army Reserve and National Guard also had voting members on the committee. The steering committee was open to all DOD elements. Official liaison members from the Air Force and Navy also participated in the steering committee meetings.

A standard briefing procedure was established. The HQDA staff was briefed the day before the steering committee meeting. The Assistant Chief of Engineers (ACE) was briefed after steering committee meetings when major decisions were made.

The first task was to determine one set of standard definitions for use by all Army elements. A list of all current definitions was compiled and reviewed by both the research team and the steering committee member organizations independently. Many current definitions overlapped, and several required knowledge of the organization that performed the work before they could be applied.

The second task was to determine the state of the art in planning and programming maintenance in the Army, the private sector, and other Government agencies. Major Federal agencies were contacted and visited. Most agencies were not performing maintenance resource plans and program functions beyond the budget year. City and state governments were contacted as well as colleges and universities. Stanford University was the only organization found that had a long-range planning program. Several large companies and management organizations also were contacted, but none had any long-range maintenance planning programs.

The review of the current programming and planning activities within the Army showed that the installations had relatively little functional work in this area. All functional work was performed by the MACOMs and HQDA. An initiative to move the planning and programming function down to the installation level was underway within HQDA. It was expected to take at least 3 years for full implementation at the installations. The purpose of performing planning and programming at the installation level is to obtain a more accurate picture of Army needs based on the actual facilities maintained. The installations need tools to help them perform these activities. Therefore, part of this research effort was to identify the tools needed, develop computer programs to support the function, and test the prototype programs at several installations.

The first meeting of the entire steering committee was held after tasks 1 and 2 were completed. The steering committee charter and research proposal were reviewed and accepted. The results of the state-of-the-art survey were presented to the committee. The current and proposed definitions were presented and discussed. All participants could agree on using Webster's definition of maintenance, but beyond this point, there was very little agreement. Most participants could see that the terms were overlapping and in some cases cyclic in nature. However, it was agreed not to pursue standard definitions further.

The third task was to visit the 10 test installations to discuss how planning and programming functions could be performed at the installation levels. Since the installations were not currently involved in these activities, the discussions proved very interesting. All installation personnel stated that the installation was underfunded to do the work that should be performed and that the budget figures have very little to do with actual facility maintenance needs. Most installations seemed reluctant to consider performing this new function, citing personnel shortages and a lack of knowledge about their facilities as the two major problems. The installations were willing to work with the researchers to develop and test new functions on a limited basis.

The fourth task was to discuss the future of maintenance planning and programming functions with the HQDA staff. There was a general consensus that the functional area was not receiving adequate attention from the Army and that the functions should be extended to the installations in the near future. The timeframe for extending the function to the installations was unknown.

The fifth task was to develop a set of alternative maintenance resource prediction models and to discuss the pros and cons of each model. The results of this effort are given in Appendix B.

The steering committee met again to review current planning and programming functions and six alternative models. The committee voted to use the historical funding model as an interim solution until a model based on facility components could be produced. The fixed percentage of current replacement cost model was also to be pursued. A fast program based on the results of the component model was needed at HQDA.

The sixth task was to develop several data bases that could be applied within the prediction models. The development of each data base is described in Chapter 3.

The seventh task was to develop several sets of maintenance resource prediction models. The models would span the range of possible data input from the simplest, with very little input, to the most complex with a large amount of detail. One purpose of the large number of model sets was to explore the effect of the input data complexity on the accuracy of the results. The complete set of models developed are described in Chapter 4. The computer systems are discussed in Chapter 5.

A third steering committee meeting was held at this point to select the facility category codes to be modeled for the first test of the prototype Maintenance Resource Prediction Model (MRPM). The decision was made to address buildings initially as buildings account for over 60 percent of the maintenance expenditures annually. Family housing and unaccompanied personnel housing were selected since the two combined categories account for 26 percent of yearly maintenance expenditures. These two current use categories were to be modeled completely by USACERL and the results reviewed by the steering committee.

The eighth task was to test the models at all organizational levels within the Army and to revise the data base and process based on the results. Tests were performed using four different complementary methods. The first test consisted of sampling family housing and barracks at each of the 10 test sites. USACERL collected and entered all facility component and cost data for the models, ran the models, and presented the results to each installation.

The steering committee met again to review the results of the family housing and unaccompanied personnel housing test results. The steering committee believed that it could not make a final decision based on such a small and limited test scope. The general consensus was to continue the research by sampling other current use building facility category codes at the six U.S. test installations. The steering committee voted to provide each test installation with a personal computer (PC) to perform a hands-on test. This was the second level of testing.



A meeting of MPRM users (Forts Bragg, Leonard Wood, Devens, and Ord) was held to discuss progress and determine if the installations could make a decision about implementing the system. It was agreed that the MPRM should be implemented fully, covering all facilities at installations, before a recommendation could be made on fielding the model. Funding was received to fully implement the MPRM at Forts Bragg, Leonard Wood, Devens, and Ord.

The third test was to completely model four installations in the United States (Forts Bragg, Leonard Wood, Ord, and Devens) and Wuerzburg in Germany. Test results were to be used in planning the expansion and future implementation of the system. Concurrent with this test, a fourth series of tests was performed by other organizations involved in the planning and programming functions. The MPRM research was used by two Government contractors performing work on historic family houses. The research was also used by contractors involved in the long-range stationing study (LRSS) and a total Army Real Property Planning system (RPLANS).

The ninth task in this project was to perform an 80-year or 120-year analysis on each of the facilities modeled. The purpose of this analysis was to develop a summary prediction model based solely on the facility's age, floor area, and current use. This research is described in Chapter 3.

The tenth and final step in the basic research program was for the steering committee to evaluate all tests and make a recommendation on the direction the Army should move in planning and programming functions and support. The results of this step are described in Chapter 6.

### Products and Reports Published

This is one of several reports addressing maintenance resource prediction in the facility life-cycle process. This report presents the scope of the total research effort. Figure 1 shows the relationships between the products and reports developed during this research project.

The first research product is a data base containing the labor, material and equipment resources required to perform maintenance tasks related to every building construction component (Figure 1, Task Resource Data Base). This data base includes labor hour, Washington, DC material costs, and equipment hour resource information. The frequency of task occurrence is also given. This information is published as a series of four Special Reports by engineering system: (1) architectural, (2) heating, ventilating, and air-conditioning (HVAC), (3) plumbing, and (4) electrical.<sup>2</sup> The title for the series is "Maintenance Task Data Base for Buildings." Figure 2 shows an example from this data base. This data is also available in electronic form. The data base is used within the MPRM Individual Facility Component System which operates on a PC with the IBM Disk Operating System (DOS). This program allows a facility to be defined by entering the components and component quantities that comprise the facility. The tasks are used to determine the resources required annually to keep the facility maintained. Engineered Performance Standards (EPS) were used to generate task data. A typical EPS task is shown in Table 1.

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<sup>2</sup>E.S. Neely et al., *Maintenance Task Data Base for Buildings: Architectural Systems*, Special Report P-91/23 (U.S. Army Construction Engineering Research Laboratory [USACERL], May 1991); E.S. Neely et al., *Maintenance Task Data Base for Buildings: Heating, Ventilation, and Air-Conditioning Systems*, Special Report P-91/21 (USACERL, May 1991); E.S. Neely et al., *Maintenance Task Data Base for Buildings: Plumbing Systems*, Special Report P-91/18 (USACERL, May 1991); E.S. Neely et al., *Maintenance Task Data Base for Buildings: Electrical Systems*, Special Report P-91/25 (USACERL, May 1991).

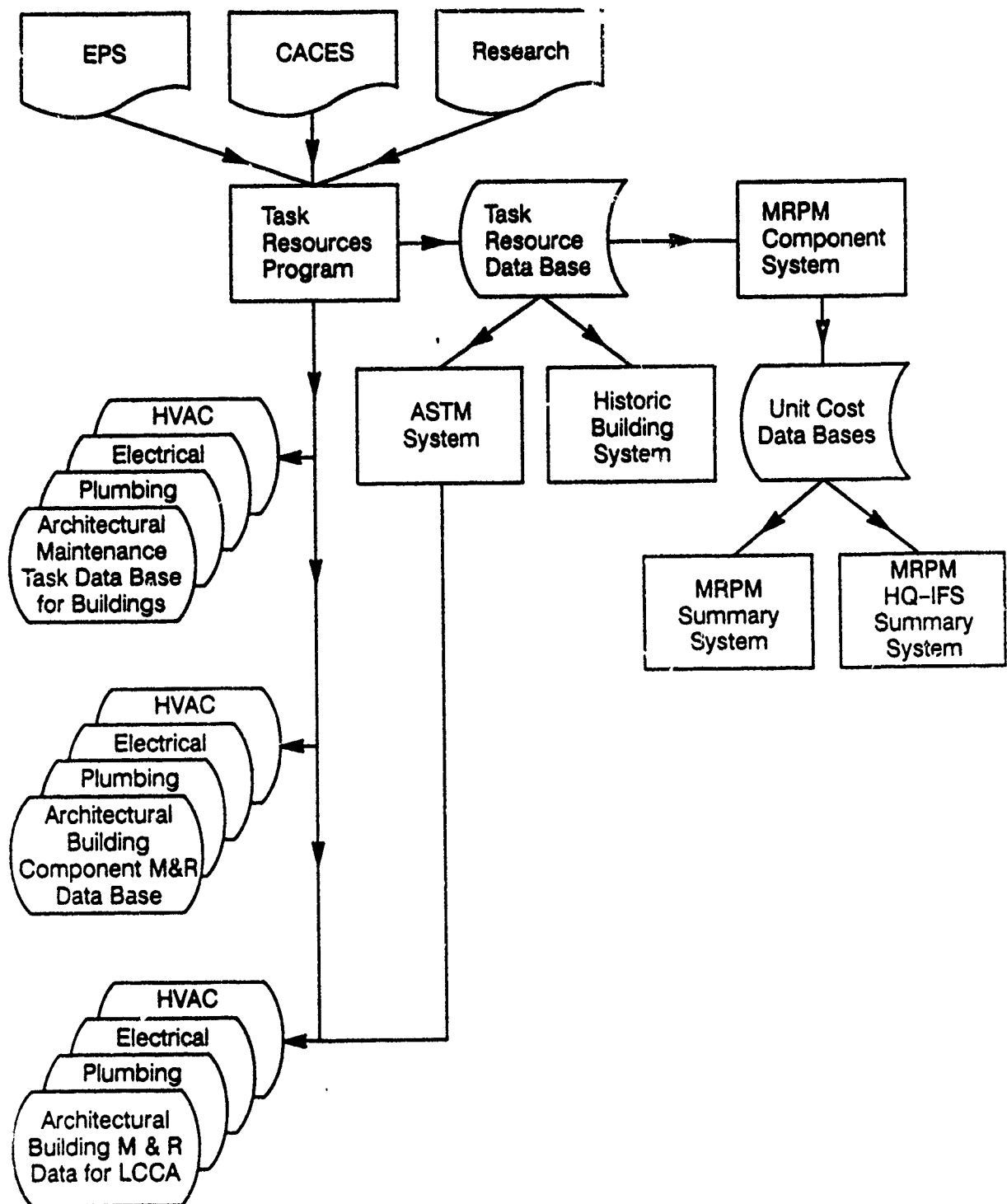


Figure 1. Maintenance reports for buildings.

# TASK DATA FORM

Task Code: 0311356

Component: SHINGLES System: ROOFING Subsystem: ROOF COVERING  
 Task Description: REPLACE NEW OVER EXISTING - SHINGLED ROOF  
 Unit of Measure: SQUARE FEET Frequency of Occurrence H: 18.00 A: 20.00 L: 22.00  
 Persons per Team: 2 Task Duration: 0.0150 hours Once every (H,A,L) years  
 Trade: ROOFER Task Classification: 1

## Labor Resources

Subtask Description	
1. SET UP/SECURE/TAKE DOWN LADDER	0.000160
2. REPLACE WITH NEW SHINGLE	0.012887
3. CLEAN UP	0.010000

## Material Resources

Description	Quantity	Unit Cost
SHINGLE	1.0 SF	0.2600
MASTIC	1.0 SF	0.1500
		0.4100

## SUMMARY

Resources UOM	Direct	Indirect	Total
Labor Hours	0.023047	0.006914	0.029961
Material Cost \$	0.410000		0.410000
Equipment Hours			0.014981

Figure 2. Typical task data form.

**Table 1**  
**Typical EPS Task Format\***

No.	Work Unit Description	Hours
1	Remove and Install Screw	0.32040
2	Remove and Install Panel	0.29280
3	Lube Bearings, Fan, Motor, Pump	0.07260
4	Adjust Belt Tension	0.10200
5	Adjust Float	0.04000
6	Sensory Inspect Bearings	0.25260
7	Fill Out Inspector Report	0.01375
	Total	1.09415

\*Task: recurring maintenance--evaporative condenser or metal cooling tower (25-ton and over air-conditioning system).

The second research product is a component resource summary using the task data developed in the first product. The component resource summary covers the first 25 years of a facility's life. The tasks for the component were scheduled and combined into one set of annual resource requirements. This annual resource information is published as a series of four Special Reports<sup>3</sup> titled "Building Component Maintenance and Repair Data Base." An example from this data base is shown in Table 2. The data base is also available in electronic form. This data can be used to perform special economic analyses such as one for a 20-year life using a 10 percent discount rate.

The third research product is a set of 25-year present worth factor tables. The component data developed in the second product was used to form a set of 25-year present worth factor tables for use by designers in component selection for discount rates of 7 and 10 percent. The annual component resource values were multiplied by the appropriate present worth factor and added for the 25 years to produce one

<sup>3</sup> E.S. Neely et al., *Building Component Maintenance and Repair Data Base: Architectural Systems*, Special Report P-91/27 USACERL, May 1991; E.S. Neely et al., *Building Component Maintenance and Repair Data Base: Heating, Ventilation, and Air-Conditioning Systems*, Special Report P-91/22 (USACERL, May 1991); E.S. Neely et al., *Building Component Maintenance and Repair Data Base for Buildings: Plumbing Systems*, Special Report P-91/30 (USACERL, May 1991); E.S. Neely et al., *Building Component Maintenance and Repair Data Base: Electrical Systems*, Special Report P-91/19 (USACERL, May 1991).

Table 2

## Typical Component Summary

## 25 YEAR COMPONENT LISTING

Cases No.: 031134 - Roll Roofing      031135 - Shingles

LABOR HOURS	MATERIAL \$	EQUIPMENT HOURS	YR	LABOR HOURS	MATERIAL \$	EQUIPMENT HOURS
0.0076	0.0165	0.0039	1	0.0024	0.0220	0.0013
0.0076	0.0165	0.0039	2	0.0024	0.0220	0.0013
0.0090	0.0165	0.0046	3	0.0026	0.0220	0.0014
0.0076	0.0165	0.0039	4	0.0024	0.0220	0.0013
0.0076	0.0165	0.0039	5	0.0032	0.0330	0.0017
0.0090	0.0165	0.0046	6	0.0026	0.0220	0.0014
0.0076	0.0165	0.0039	7	0.0024	0.0220	0.0013
0.0076	0.0165	0.0039	8	0.0024	0.0220	0.0013
0.0090	0.0165	0.0046	9	0.0026	0.0220	0.0014
0.0414	0.7496	0.0207	10	0.0032	0.0330	0.0017
0.0076	0.0165	0.0039	11	0.0024	0.0220	0.0013
0.0076	0.0165	0.0039	12	0.0026	0.0220	0.0014
0.0090	0.0165	0.0046	13	0.0024	0.0220	0.0013
0.0076	0.0165	0.0039	14	0.0024	0.0220	0.0013
0.0076	0.0165	0.0039	15	0.0034	0.0330	0.0018
0.0090	0.0165	0.0046	16	0.0024	0.0220	0.0013
0.0076	0.0165	0.0039	17	0.0024	0.0220	0.0013
0.0076	0.0165	0.0039	18	0.0026	0.0220	0.0014
0.0090	0.0165	0.0046	19	0.0024	0.0220	0.0013
0.0414	0.7496	0.0207	20	0.0332	0.4675	0.0167
0.0076	0.0165	0.0039	21	0.0026	0.0220	0.0014
0.0076	0.0165	0.0039	22	0.0024	0.0220	0.0013
0.0090	0.0165	0.0046	23	0.0024	0.0220	0.0013
0.0076	0.0165	0.0039	24	0.0026	0.0220	0.0014
0.0076	0.0165	0.0039	25	0.0032	0.0330	0.0017

set of resource values. This information is published as a series of four reports<sup>4</sup> titled "Building Maintenance and Repair Data for Life-Cycle Cost Analyses." Table 3 shows an example from this data base. The data base is also available in electronic form.

The first three resource columns provide data to allow the designer to calculate the life-cycle costs at any location by multiplying by the correct labor rate, equipment rate, and material geographic location factor. This multiplication and addition have been performed for the Military District of Washington, DC, and are given in the fourth column of the table. The right section of the table is information that can be entered into computer systems that perform life-cycle cost analysis.

The fourth research product is a task resource maintenance computer program. This program is written in DBASE III. This program maintains the task data base and produces task, component, and life-cycle cost tables. User's and programmer's manuals are published as USACERL ADP Reports.

The fifth research product is the MRPM Individual Facility computer system. This system operates on a DOS PC system that allows facilities to be modeled by entering their components. Resource predictions are produced by applying the individual tasks and then forming resource summaries by subsystems, systems, facilities, installations, reporting installations, MACOM, and Army. User's and programmer's manuals are published as USACERL ADP Reports<sup>5</sup>.

The sixth research product is the MRPM Facility Summary computer system. Two summary systems have been implemented. One summary system is a module of HQ-IFS. The second is a DOS PC based system. Both are macro-level computer systems developed for installations, HQDA, and the MACOMs. The macro-level system uses the most basic data contained in the current facility real property inventory files: (1) current facility use, (2) floor area, and (3) construction date. User's and programmer's manuals for the systems are published as a USACERL ADP Reports<sup>6</sup>.

The seventh research product is an analysis of the resources to maintain buildings by current use. This is summary data of the individual facility information obtained by use of the component model at several installations. The results of this research are published in two USACERL Special Reports<sup>7</sup>.

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<sup>4</sup> R.D. Neathammer et al., *Building Maintenance and Repair Data for Life-Cycle Cost Analyses: Architectural Systems*, Special Report P-91/17 (USACERL, May 1991); E.S. Neely et al., *Building Maintenance and Repair Data for Life-Cycle Cost Analyses: Heating, Ventilation, and Air-Conditioning Systems*, Special Report P-91/20 (USACERL, May 1991); E.S. Neely et al., *Building Maintenance and Repair Data for Life-Cycle Cost Analyses: Plumbing Systems*, Special Report P-91/24 (USACERL, May 1991); E.S. Neely et al., *Building Maintenance and Repair Data for Life-Cycle Cost Analyses: Electrical Systems*, Special Report P-91/26 (USACERL, May 1991).

<sup>5</sup> E.S. Neely et al., *Maintenance Resource Prediction Model (MRPM) Individual Facility System User's Manual*, ADP Report P-91/12 (USACERL, January 1991); E.S. Neely et al., *Maintenance Resource Prediction Model (MRPM) Individual Facility System Programmer's Manual*, Special Report P-91/28 (USACERL, March 1991).

<sup>6</sup> E.S. Neely et al., *Maintenance Resource Prediction Model Summary System (MRPMSS) User's Manual*, ADP Report P-91/03 (USACERL, October 1990); E.S. Neely et al., *Maintenance Resource Prediction Model Summary System (MRPMSS) Programmer's Manual*, Draft USACERL Report; E.S. Neely et al., *HQ-IFS Maintenance Resource Prediction Model (MRPM) User's Manual*, ADP Report P-91/04 (USACERL, October 1990); E.S. Neely et al., *HQ-IFS Maintenance Resource Prediction Model (MRPM) System Manual*, ADP Report P-91/02 (USACERL, October 1990).

<sup>7</sup> E.S. Neely et al., *Maintenance Resources by Building Use for U.S. Army Installations*, Special Report P-91/29 (USACERL May 1991).

Table 3

## Life-Cycle Cost Analysis

EPS BASED MAINTENANCE AND REPAIR COST DATA FOR USE IN LIFE CYCLE													COST ANALYSIS (\$ PER UNIT MEASURE)					PAGE 1				
COMPONENT DESCRIPTION		PRESENT WORTH OF ALL 25 YEAR MAINT. AND REPAIR COSTS (d-10%)					ANNUAL MAINTENANCE AND REPAIR PLUS HIGH COST REPAIR AND REPLACEMENT COSTS															
		By Resources					Wash. D.C. Total	Annual Maintenance and Repair			Replacement and High Cost Tasks											
		Labor	Mat'l	Equip.	Labor	Mat'l		Equip.	Yr	Labor	Mat'l	Equip.										
ARCHITECTURE		UM																				
ROOFING																						
BUILTUP ROOFING																						
PLACE NEW MEMBRANE OVER EXISTING -BUILTUP		SF	0.03990	0.37220	0.02000		1.25															
MOD. BIT./THERMOPLASTIC MEMBRANE REPLACEMENT OR REPAIR - M.B./T. R		SF	0.02440	0.33090	0.01180		0.87															
THERMOSETTING MEMBRANE REPLACEMENT - THERMOSETTING ROOF		SF	0.01680	0.23950	0.00850		0.61															
SLATE		SF	0.01850	0.10440	0.00890		0.51															
CEMENT ASBESTOS TILE		SF	0.01820	0.24340	0.00870		0.64															
ROLL ROOFING		SF	0.01550	0.20990	0.00740		0.55															
TOTAL ROOF REPLACEMENT - ROLL ROOF		SF	0.07140	0.42700	0.03640		2.00															
SHINGLES		SF	0.02210	0.22150	0.01170		0.71															
REPLACE NEW OVER EXISTING - SHINGLED ROOF		SF	0.01460	0.11060	0.00740		0.43															
METAL		SF	0.02190	1.15340	0.01080		1.64															
FIBERGLASS RIGID STP. ROOF		SF	0.04300	0.11750	0.02120		1.07															
CONCRETE, SEALED PANEL ROOF		SF	0.03900	0.08410	0.02020		0.95															
CONCRETE, SEALED PANEL RF-4		SF	0.09830	0.63020	0.04950		2.80															
CONCRETE SEALED POURED FIBERGLASS, RIGID ROOF		SF	0.03800	1.15340	0.01930		1.99															
TOTAL ROOF REPLACEMENT - FIBERGLASS RIGID		SF																				

See NOTES on the last page of this table for Explanation of Column Headings

See NOTES on the last page of this table for Explanation of Column Headings

APPENDIX F  
FACILITIES DATA



## STEP II SUBMISSION

CR23-484

1. Activity SHDL No.	Activity Name and Location	Date Submitted
000210		JUN 10 1987
2. Project No.	Title	
	REPAIR RAMPS, APPLIED INSTRUCTION, BLDG. 621	
3. Type		
a. <input checked="" type="checkbox"/> Maint/Repair	b. <input type="checkbox"/> Minor Construction/ Alteration	c. <input type="checkbox"/> Air Conditioning
d. <input type="checkbox"/> Equipment Installation		
4. Describe and State Function of Facility		
Bldg. 621 is a three story permanent structure with 118,370 square feet of area. It houses the basic Electrician and Electronic School which provides necessary training for personnel going into the rates of FT, GM, IM, IC, EM, and GSE.		
a. Prprty Rcrd Card #		
2-03224		
b. Navy Category Code		
171-20		
c. Bldg or Structure #		
Bldg. 621		
5. What is the effect of this project on the mission of the activity?		
In support of the primary mission of and adequate training school facilities. This project will restore the integrity of the ramps and exterior structural wall connection points of Bldg. 621, ET School. Is tasked to provide safe		
6. The requirement for the facility is based on		
a. <input type="checkbox"/> A change in mission	b. <input checked="" type="checkbox"/> Full time continuing need	c. <input type="checkbox"/> 3 to 5 year need
d. <input type="checkbox"/> Less than 3 years' need	e. <input type="checkbox"/> Currently required less than 50% of time	f. <input type="checkbox"/> Reserved for future requirements
7a. Est funded cost	b. Est project cost	c. Est planning cost
\$140,000	\$150,000	\$10,000
d. Total funds requested	e. Est facil repl cost	
\$150,000	\$8,565,000	
8. Date facility constructed	9. Is facility on an approved BFR? If no, how was need determined?	
1969	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	
10. Is project listed on annual inspection summary? If no, and AIS applicable, explain exclusion.		
<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Deficiency item No. S003870		
11. Describe condition/problem to be corrected/solved with solution. Additional description ONE PAGE ONLY		
Bldg. 621 has two concrete ramps 12' wide & 150' long that provide the only exterior student passage to and from the 2nd and 3rd floors. The ramps have a series of electric heaters embedded in the walkway for removing snow and ice. Both ramps have settled over the years and have traverse and longitudinal cracks. Many of the electric heaters and all of the ramp lighting are non-functional. Some of the precast concrete supports for ramps are cracked & deteriorating. This project will provide for repair of these structural deficiencies & also repair the northside retaining wall which has suffered some lateral displacement. No adverse effect on the environment is anticipated.		
12. Why is proposed solution best - and what alternatives were considered?		
This alternative is considered best because it will restore the integrity of the structure for maximum economic life at a minimum cost. Other alternatives were to replace the structure with a new one which would be costly and uneconomical, or to leave the status quo, which is unacceptable.		
13. Were there any non-Navy experts invited to review this problem and this solution? Explain effect.		
a. <input type="checkbox"/> Yes b. <input checked="" type="checkbox"/> No		
14. Has EPD design division reviewed solution?	a. <input type="checkbox"/> Yes b. <input checked="" type="checkbox"/> No	15. Can another facility be economically adapted for this function?
		a. <input type="checkbox"/> Yes b. <input checked="" type="checkbox"/> No
16. Can project be funded in phases? How? How many?		
a. <input type="checkbox"/> Yes b. <input checked="" type="checkbox"/> No		
17. This project is the result of		
a. <input type="checkbox"/> Inadequate Maintenance	b. <input checked="" type="checkbox"/> Facility Age	c. <input type="checkbox"/> Deficient Constr.
d. <input type="checkbox"/> Deficient Design	e. <input type="checkbox"/> Other	
18. Has this specific problem been corrected previously?		

NAVFAC TT0377 (1-78) **COST ESTIMATE** **Sheet 1 of 1**  
 Supercedes NAVDOCKS 2417 **Date Prepared** MAY 1987 **Identification Number**  
 Activity and Location **Construction Contract No.** N/A **R63-86**

**Estimated By** **Category Code Number**  
 171-60

**Project Title**  
 REPAIR RAMPS, APPLIED INSTRUCTION BLDG. 621 **Job Order Number** 23-484

**Status of Design**  
☐ PED ☐ 30% ☐ 100% ☐ Final ☒ Other Step II

ITEM DESCRIPTION	Quantity Number	Unit	Material Cost		Labor Cost		Engineering Estimate	
			Unit Cost	Total	Unit Cost	Total	Unit Cost	Total
1. REMOVE POWER FROM HEAT MATS ON RAMPS NORTH AND SOUTH FOR REMOVAL	1	LS	-	-	500	500	500	500
2. REMOVE CONCRETE TOPPING	6,094	SF	-	-	7.00	42,658	7.00	42,658
3. CHECK OUT ALL CONTROLS OF HEAT MATS FOR BOTH RAMPS, TIGHTEN & CLEAN ALL CONTACTS, OR INSTALL NEW	1	LS	258	258	991	991	1,249	1,249
4. INSTALL CONCRETE TOPPING	6,094	SF	1.27	7,739	1.16	7,069	2.43	14,808
5. INSTALL MEMBRANE	7,202	SF	.89	6,409	.83	5,978	1.72	12,387
6. BROKEN CONCRETE: PICK-UP THE CONCRETE & HAUL TO OFF BASE DUMP	1	LS	-	-	1,986	1,986	1,986	1,986
7. REPAIR SUPPORTS	500	SF	1.98	990	7.50	3,750	9.48	4,740
8. REPAIR AND INSTALL REGLET	1,108	SF	.80	886	4.21	4,665	5.01	5,551
9. CONCRETE PATCHING ON CONCRETE PILLARS SUPPORTING THE RAMPS	50	CY	114	5,700	139	6,950	253	12,650
10. INSTALL DRAINS & DOWN SPOUTS	136	LF	2.41	328	2.04	277	4.45	605
11. INSTALL EXPANSION JOINTS & CONSTRUCTION JOINTS	200	LF	.35	70	.45	90	.80	160
12. HEAT MATS	5,000	SF	6.38	31,900	2.18	10,900	8.56	42,800
TOTAL ENGINEERING COST							TOTAL	140,000
TOTAL ENGINEERING COST (ROUNDED)								140,000
DESIGN COST								10,000
TOTAL FUNDS REQUESTED (FY 88 DOLLARS)								150,000

INCLUDED IN LINE ITEMS IS CONTRACTORS DR & P 25% CONTINGENCY 5% AND AN AREA COST FACTOR OF 1.09% THIS ESTIMATE ACCOMPLISHED WITH MEANS ESTIMATING GUIDE AND APPLICABLE HISTORIC DATA FROM CODE 101 FILES.



23-600

1. ACTIVITY BNCL NO N00210	ACTIVITY NAME AND LOCATION	DATE SUBMITTED JUL 82
2 PROJECT NO. R17 -82	TITLE Replace Roof Membrane, Electronics School, Bldg 621	
3. TYPE a. <input checked="" type="checkbox"/> MAINT./REPAIR    b. <input type="checkbox"/> MINOR CONSTRUCTION/ ALTERATION    c. <input type="checkbox"/> AIR CONDITIONING    d. <input type="checkbox"/> EQUIPMENT INSTALLATION		
4. DESCRIBE AND STATE FUNCTION OF FACILITY Building 621 is a permanent type structure built in 1969. It is three stories high containing 118,370 square feet of floor space. It is utilized by _____ for the instruction of basic electricity, electronics and instructor training.		a. PROPERTY RECORD CARD NO 2-03224 b. NAVY CATEGORY CODE 171-20 c. BLDG. OR STRUCTURE NO 621

5. WHAT IS THE EFFECT OF THIS PROJECT ON THE MISSION OF THE ACTIVITY?

This project will renew the water-tight integrity of this roof, thus allowing to carry out its mission in a dry, safe, and adequate environment.

6. THE REQUIREMENT FOR THE FACILITY IS BASED ON

a. <input type="checkbox"/> A CHANGE IN MISSION	b. <input checked="" type="checkbox"/> FULL-TIME CONTINUING NEED	c. <input type="checkbox"/> 3 TO 5 YEAR NEED	d. <input type="checkbox"/> LESS THAN 3 YEARS NEED	e. <input type="checkbox"/> CURRENTLY REQUIRED LESS THAN 80% OF TIME	f. <input type="checkbox"/> RESERVED FOR FUTURE REQUIREMENTS
7a. EST. FUNDED COST \$ 196,700	b. EST. PROJECT COST \$ 196,700	c. EST. PLANNING COST \$ 8,000	d. TOTAL FUNDS REQUESTED \$ 204,700	e. EST. FACIL. REPL. COST \$ 7,502,000	

8. DATE FACILITY CONSTRUCTED

1969

9. IS FACILITY ON AN APPROVED BASIC FACILITY REQUIREMENTS LIST? If "NO," how was need determined?

☒ YES ☐ NO

10. IS PROJECT LISTED ON ANNUAL INSPECTION SUMMARY? answer is "NO," and AIS is applicable, explain exclusion.

☒ YES ☐ NO ☐ N.A.

11. DESCRIBE CONDITION TO BE CORRECTED, OR PROBLEM TO BE SOLVED WITH PROPOSED SOLUTION. Attach additional description if necessary. ONE PAGE ONLY.

SEE ATTACHED

12. WHY IS THE PROPOSED SOLUTION BEST - AND WHAT ALTERNATIVES WERE CONSIDERED?

This is the only solution considered, since the insulation is approximately 90% saturated and there are inadequate expansion and control joints.

13. WERE ANY NON-NAVY EXPERTS INVITED TO REVIEW THIS PROBLEM AND THIS SOLUTION? Explain effect on solution.

a. ☐ YES b. ☒ NO

14. HAS EFD DESIGN DIVISION REVIEWED SOLUTION?

a. ☐ YES b. ☒ NO

15. CAN ANOTHER FACILITY BE ECONOMICALLY ADAPTED FOR THIS FUNCTION?

a. ☐ YES b. ☒ NO

16. CAN PROJECT BE FUNDED IN PHASES? How? How many?

a. ☐ YES b. ☒ NO

17. THIS PROJECT IS THE RESULT OF

a. ☐ INADEQUATE MAINTENANCE b. ☒ FACILITY AGE c. ☐ DEFICIENT CONSTR. d. ☒ DEFICIENT DESIGN e. ☐ OTHER: \_\_\_\_\_

18. HAS THIS SPECIFIC PROBLEM BEEN CORRECTED PREVIOUSLY?

a. ☐ YES b. ☒ NO When?

HOW LONG WILL PROPOSED CORRECTIVE ACTION LAST? 20 YEARS

Replace Roof Membrane, Electronics School, Bldg. 621

Block 11

The original building (225'-8" x 134'-6") and penthouse has a concrete roof deck, overlayed with lightweight concrete that is pitched to the drains. The addition (106'-0" x 64'-6") has a concrete deck with 4 1/2" of insulation which is tapered and pitched to the drains. The only expansion joint on the entire roof is at the junction between the two buildings. This lack of expansion joints or control joints in the roof membrane system has caused excessive cracking in the field and loosening of flashing at the edges. Leakage to the interior is significant causing erosion to the building structure as well as damage to Class III property. In some cases, water has shorted out light fixtures which started small fires.

This project proposes to remove the existing built-up roof membrane and fiber insulation, which is saturated and replace the entire roofing system. During the installation of the new roofing, expansion joints will be constructed to correspond with the structural expansion joints. Lightweight concretes are to be cut at these joints. Additionally, area dividers will be placed in the new system in such a manner as to divide the roof area into seven "zones." Each zone is to receive a single ply elastomeric membrane with stone ballast. New flashing will be installed at the parapet and penthouse walls. The existing raglet is too shallow and must be cut deeper. Recommend the new flashing be secured in the raglet with lead wool and caulking. A double layer of membrane (full mopped) will be installed in the cooling tower area. Traffic planks (walkway) will be installed around the cooling tower.

APPENDIX G

HEAT DISTRIBUTION SYSTEMS DATA

(SOURCE: PARSONS 1986)

(SOURCE: PAN AM WORLD SERVICES 1985)

1521

## COST DATA FOR HEAT DISTRIBUTION SYSTEMS

	PAGE
COST FOR LOCATING DIRECT BURIED REPAIR.....	34
COST FOR LOCATING SHALLOW TRENCH REPAIR.....	37
COST FOR REPAIR OF DIRECT BURIED.....	44
COST FOR REPAIR OF SHALLOW TRENCH.....	47
CONSTRUCTION COSTS FOR DIRECT BURIED.....	49
CONSTRUCTION COSTS FOR SHALLOW TRENCH.....	54
LIFE-CYCLE COST FOR 8 in. dia. DIRECT BURIED.....	58
LIFE-CYCLE COST FOR 8 in. dia. SHALLOW TRENCH.....	59

TABLE 7-5

LOCATING FAILURE - DIRECT BURIED

(Actual)

## SCOPE OF WORK:

Location of failure from detection to digging and backfilling not including repair of condensate line (locating done with system on)

## MANPOWER:

- 1 foreman (Heat Shop)
- 1 work leader (Heat Shop)
- 2 craftsmen (Heat Shop)
- 1 backhoe operator (Roads & Grounds Shop)
- 2 carpenters (Carpentry Shop)
- 2 plumbers (Heat Shop)
- 1 welder (Sheet Metal Shop)

## PROCEDURE:

	<u>Approximate Time Involved (Manhours)</u>
1. Failure is detected by craftsman	0.3
2. Inspection of two manholes is performed by two craftsmen (1 inside, 1 out) who check conduit for leaks	4.0
3. Detected failure is reported by craftsman to supervisor	1.0
4. Valves are closed at each of the two manholes to isolate section by two craftsmen	1.0
5. Digging permit is processed by craftsman	8.0
6. Backhoe is moved to digging site	0.5
7. Foreman is assigned for commencement of project	1.0
8. Work leader assigned for duration of project	8.3

TABLE 7-5 (Cont)

PROCEDURE:

	<u>Approximate Time Involved (Manhours)</u>
9. Five 10-foot-long sections are excavated exposing conduit system	8.3
10. Two plumbers remove water and mud from pit as it accumulates	8.3
11. Two carpenters shore walls of excavation	3.3
12. A window is cut in conduit to determine direction of flow of condensate (5 times)	2.5
13. Edges of window are ground and conduit section is replaced and rewelded (4 times, fifth time section will be removed)	8.0
14. Mastic coating is applied (4 times)	1.0
15. Backfilling after repair	4.0
16. Landscaping	2.0



TABLE 7-6  
COST FOR LOCATING FAILURE - DIRECT BURIED  
 (Actual)

	<u>Manhours</u>	<u>Labor Rate</u>	<u>Cost</u>
1.	0.3	28.45	7.11
2.	4.0	28.45	113.80
3.	1.0	28.45	28.45
4.	1.0	28.45	28.45
5.	8.0	28.45	227.60
6.	0.5	29.10	14.55
7.	1.0	31.35	31.35
8.	8.3	28.45	236.99
9.	8.3	29.10	242.40
10.	8.3	31.75	264.48
11.	3.3	27.70	92.24
12.	2.5	31.55	78.88
13.	8.0	31.55	252.40
14.	1.0	31.55	31.55
15.	4.0	29.10	116.40
16.	2.0	28.45	56.90
			<u>\$1,823.55</u>
½ cy backhoe (\$250/day)			500.00
			<u>\$2,323.55</u>
			\$2,325/failure

TABLE 7-7  
LOCATING FAILURE - SHALLOW TRENCH  
 (Actual)

SCOPE OF WORK:

Location of failure from detection to removing and replacing lids not including repair of condensate line (locating done with system on)

MANPOWER:

1 backhoe operator (Roads & Grounds Shop)  
 2 craftsmen

PROCEDURE:

	<u>Approximate Time Involved (Manhours)</u>
1. Failure is detected by craftsman	0.3
2. Detected failure is reported by craftsman to supervisor	1.0
3. Backhoe is located at digging site	0.5
4. Top soil is removed from surface of lids by two craftsmen to expose lids	1.5
5. Three lids removed to locate failure (backhoe operator and 1 craftsman)	1.5
6. Lids are replaced after repair (backhoe operator and 1 craftsman)	1.5
7. Lids are resealed by two craftsmen	1.5
8. Landscaping	1.5

TABLE 7-8

COST FOR LOCATING FAILURE - SHALLOW TRENCH

(Actual)

	<u>Manhours</u>	<u>Labor Rate</u>	<u>Cost</u>
1.	0.3	28.45	7.11
2.	1.0	28.45	28.45
3.	0.5	29.10	14.55
4.	1.5	28.45	42.68
5.	1.5	29.10	43.66
6.	1.5	29.10	43.66
7.	1.5	28.45	42.68
8.	1.5	28.45	42.68
			<u>\$265.46</u>
$\frac{1}{2}$ cy backhoe (\$250/day)			<u>250.00</u>
			<u>\$515.46</u>
			\$515/failure

Pages 39 thru 43 is  
not available

TABLE 7-13  
REPAIR OF FAILURE - DIRECT BURIED  
 (Actual)

SCOPE OF WORK:

Repair of 15 feet of condensate line (4-inch diameter)

MANPOWER:

2 plumbers (Heat Shop)  
 1 welder (Sheet Metal Shop)  
 1 backhoe operator (Roads & Grounds Shop)

PROCEDURE:

Approximate Time  
Involved (Manhours)

- |   |     |
|---|-----|
| 1. Conduit and condensate line is severed at two ends by welder (conduit is cut deeper into existing pipeline in order to expose condensate line)   | 2.0 |
| 2. Failed section is removed by backhoe   | 1.0 |
| 3. New section is located on site by backhoe  | 1.0 |
| 4. Condensate line is aligned and tack welded in place (2 ends)   | 4.0 |
| 5. Piping is completely welded (2 ends)   | 6.0 |
| 6. Two plumbers pressurize line to check for leaks at welds   | 4.0 |
| 7. Sheet metal shop prepares two 10-gage sheet metal sections (cut & roll)  | 3.0 |
| 8. Insulation is applied to open ends of replaced section where condensate line is still exposed. Sheet metal is installed and tack welded (2 ends) | 8.0 |

TABLE 7-13 (Cont)

PROCEDURE:

	<u>Approximate Time Involved (Manhours)</u>
9. Mastic coating is removed from ends of existing conduit. Sheet metal is completely welded (2 sides of sheet metal, 2 ends)	8.0
10. Mastic coating is reapplied (2 ends)	2.0

TABLE 7-14  
COST FOR REPAIR - DIRECT BURIED  
 (Actual)

	<u>Manhours</u>	<u>Labor Rate</u>	<u>Cost</u>
1.	2.0	31.45	63.10
2.	1.0	29.10	29.10
3.	1.0	29.10	29.10
4.	4.0	31.55	126.20
5.	6.0	31.55	189.30
6.	4.0	31.55	126.20
7.	3.0	31.55	94.65
8.	8.0	31.55	252.40
9.	8.0	31.55	252.40
10.	2.0	28.45	56.90
			<u>\$1,219.35</u>

(15 ft of pre-fab conduit: Sched. 80 pipe,  
 1½" cal sil, 1" air gap, 10-gage C.S.  
 conduit. Material only w/fittings \$56.67/ft) 850.05

Note: Cost for renting  
 backhoe reflected in  
 locating cost

\$2,069.35

\$2,070/failure

TABLE 7-15  
REPAIR OF FAILURE - SHALLOW TRENCH  
 (Actual)

SCOPE OF WORK:

Repair of 15 feet of condensate line (4-inch diameter)

MANPOWER:

2 plumbers (Heat Shop)  
 1 welder (Sheet Metal Shop)  
 1 backhoe operator (Roads & Grounds Shop)

PROCEDURE:

	<u>Approximate Time Involved (Manhours)</u>
1. Insulation is removed from piping	0.5
2. Condensate line is severed at two ends by welder.	2.0
3. Failed section is removed by backhoe	1.0
4. New section is located on site by backhoe	1.0
5. Condensate line is aligned and tack welded in place (2 ends)	4.0
6. Piping is completely welded (2 ends)	6.0
7. Two plumbers pressurize line to check for leaks at welds	4.0
8. New insulation is installed	1.5



TABLE 7-16  
COST FOR REPAIR - SHALLOW TRENCH  
 (Actual)

	<u>Manhours</u>	<u>Labor Rate</u>	<u>Cost</u>
1.	0.5	28.45	14.23
2.	2.0	31.55	63.10
3.	1.0	29.10	29.10
4.	1.0	29.10	29.10
5.	4.0	31.55	126.20
6.	6.0	31.55	189.30
7.	4.0	31.55	126.20
3.	1.5	28.45	42.68
			<u>\$619.91</u>

(15 ft of piping: Sched 80, 1½" cal sil insul. Material only w/fittings \$15.73/ft)	<u>235.95</u>
	<u>\$855.86</u>

Note: Cost for renting backhoe  
 reflected in locating cost

\$855/failure

# ANALYSIS OF VARIOUS DIRECT BURIED HEAT DISTRIBUTION SYSTEMS

## RECAPITULATION

### STEAM

1" Steam Supply - 1" Condensate Return	154.60
1-1/2" Steam Supply - 1" Condensate Return	159.77
2" Steam Supply - 1" Condensate Return	150.71
3" Steam Supply - 1-1/2" Condensate Return	174.22
4" Steam Supply - 2" Condensate Return	182.14
6" Steam Supply - 3" Condensate Return	227.70
8" Steam Supply - 4" Condensate Return	277.12
10" Steam Supply - 6" Condensate Return	333.03
12" Steam Supply - 6" Condensate Return	358.66

### HIGH TEMPERATURE HOT WATER

1" Supply/Return *)	146.40
1-1/2" Supply/Return *)	155.22
2" Supply/Return *)	156.80
3" Supply/Return *)	172.12
4" Supply/Return *)	180.24
6" Supply/Return	266.05
8" Supply/Return	338.93
10" Supply/Return	409.39
12" Supply/Return	443.88

\*) Supply & Return pipes in the same conduit

Note that all costs are in \$/LF

ANALYSIS OF VARIOUS SIZED DIRECT BURIED CONDUIT HEAT DISTRIBUTION SYSTEMS  
STEAM SYSTEM, 12" SUPPLY 6" RETURN

<u>DESCRIPTION</u>	<u>QUANTITY &amp; UNIT</u>	<u>UNIT LABOR (\$)</u>	<u>TOTAL LABOR (\$)</u>	<u>UNIT MATERIAL &amp; EQUIPMENT</u>	<u>TOTAL MATERIAL &amp; EQUIPMENT</u>	<u>GROUP TOTAL</u>
<u>CIVIL WORK</u>						
Strip & Store Topsoil	0.17 CY	\$ 1.75	\$ 0.30	1.00	\$ 0.17	
Excavate & Stock Pile	1.15 CY	3.90	4.49	8.20	9.43	
Excav. & Haul from Site	0.59 CY	5.93	3.50	11.08	6.54	
Select Backfill (Sand)	0.05 CY	10.50	0.53	7.50	0.38	
Backfill & Compact	1.15 CY	11.71	13.47	3.15	3.62	
Repave Road Crossings	1.14 SF	0.90	1.03	0.50	0.17	
Respread Topsoil	0.17 CY	1.50	0.26	1.00	0.17	
Seed	0.70 SY	0.30	0.21	0.35	0.25	\$ 44.92
			<u>21.79</u>		<u>21.13</u>	
					<u>23.24</u>	
					<u>44.92</u>	
<u>MECHANICAL WORK (Excl. Pipe)</u>						
Install Manholes	1 LF	3.40	3.40	38.66	38.66	
Cathodic Protection	1 LF	2.80	2.80	3.10	5.90	
Air Pressure Test	1 LF	0.38	0.38	0.10	0.10	48.44
Subtotal - Cost						93.36
Subcontractor's O&P @ 20%						18.67
Subtotal						112.03
 Prime Contractors O&P @ 5%						
						5.60
TOTAL (\$/LF)						117.63

34/0  
38.66  
42.06  
5.00  
20.00

Using the same estimating procedure for civil work and mechanical work excluding piping, the following costs are obtained:

STEAM	
<u>Nom. pipe diam. (supply)</u>	<u>Cost (incl. overhead &amp; profit)</u>
1"	\$91.67
1-1/2	91.67
2	91.67
3	91.67
4	91.67
6	91.67
8	98.73
10	104.53
12	109.82
	117.63

HOT WATER	
<u>Nom. pipe diam. (supply)</u>	
1	91.67
1-1/2	91.67
2	91.67
3	91.67
4	91.67
6	91.67
8	107.18
10	109.82
12	123.63
	128.13

# DIRECT BURIED CONDUIT - STEAM DISTRIBUTION SYSTEM

(Prices include fittings, valves, elbows, endplates, drain plugs, freight, welding equipment, installation supervision)

Pipe Diameter (in)	Supply Pipe (Sched. 40)	Return Pipe (Sched. 40)	Installation*)	Subtotal	Subcontr. O&P @ 20%	Subtotal	Prime Contr. O&P @ 5%	Total
1	24.46	23.63	1.85	49.94	9.99	59.93	3.00	62.93
1-1/2	28.57	23.63	1.85	54.05	10.81	64.86	3.24	68.10
2	29.31	23.63	1.85	54.79	10.96	65.75	3.29	69.04
3	35.93	26.82	2.77	65.52	13.10	78.62	3.93	82.55
4	39.30	29.03	3.47	71.80	14.36	86.16	4.31	90.47
6	60.73	37.01	4.62	102.36	20.47	122.83	6.14	128.97
8	87.45	42.60	6.93	136.98	27.40	164.38	8.21	172.59
10	108.77	59.13	9.25	177.15	35.43	212.58	10.63	223.21
12	118.30	59.13	13.86	191.29	38.26	229.55	11.48	241.03

\*) Includes stringing, welding, hydrostatic tests & coating

Note: All Prices in \$/LF

DIRECT BURIED CONDUIT - HIGH TEMPERATURE HOT WATER DISTRIBUTION SYSTEM

(Prices include fittings, valves, elbows, endplates, drain plugs, freight, welding and Equipment, installation supervision)

Pipe Diameter (in)	Supply Pipe (Sched. 40)	Return Pipe (Sched. 40)	Instal- lation	Subtotal	Subcontr. O&P @ 20%	Subtotal	Prime Contr. O&P @ 5%	Total
1	20.79	20.79	1.85	43.43	8.69	52.12	2.61	54.73
1-1/2	24.29	24.29	1.85	50.43	10.09	60.52	3.03	63.55
2	24.91	24.91	1.85	51.69	10.34	62.03	3.10	65.13
3	30.54	30.54	2.77	63.85	12.77	76.62	3.83	80.45
4	33.41	33.41	3.47	70.29	14.06	84.35	4.22	88.57
6	60.73	60.73	4.62	126.08	25.22	151.30	7.57	158.87
8	87.45	87.45	6.93	181.83	36.37	218.20	10.91	229.11
10	108.77	108.77	9.25	226.79	45.36	272.15	13.61	285.76
12	118.30	118.30	13.86	250.46	50.09	300.55	15.03	315.58

\*) Includes stringing, welding, hydrostatic tests, coating

Note: All prices in \$/LF

COST SUMMARY SHEET  
CONCRETE SHALLOW TRENCH

STEAM

1" Steam Supply - 1" Condensate Return	274.25
1-1/2" Steam Supply - 1" Condensate Return	275.83
2" Steam Supply - 1" Condensate Return	275.85
3" Steam Supply - 1-1/2" Condensate Return	296.25
4" Steam Supply - 2" Condensate Return	305.09
6" Steam Supply - 3" Condensate Return	350.19
8" Steam Supply - 4" Condensate Return	366.39
10" Steam Supply - 6" Condensate Return	416.57
12" Steam Supply - 6" Condensate Return	433.21

HIGH TEMPERATURE HOT WATER

1" Supply/ Return	274.16
1-1/2" Supply/Return	277.33
2" Supply/Return	277.37
3" Supply/Return	315.93
4" Supply Return	329.04
6" Supply Return	377.56
8" Supply Return	396.44
10" Supply/Return	443.55
12" Supply/Return	476.63

Note that all costs are in \$LF

COST ESTIMATE FOR A COMPLETE SHALLOW TRENCH STEAM DISTRIBUTION SYSTEM,  
12" STEAM SUPPLY, 6" CONDENSATE RETURN

<u>CONCRETE TRENCH</u>	<u>QUANTITY &amp; UNIT</u>	<u>UNIT LABOR \$</u>	<u>TOTAL LABOR (\$)</u>	<u>UNIT MATERIAL &amp; EQUIPMENT</u>	<u>TOTAL MATERIAL &amp; EQUIPMENT</u>	<u>GROUP TOTAL</u>
Strip & Store Topsoil	0.26 CY	1.75	0.46	1.00	0.26	
Excavate & Stockpile	1.07 CY	3.90	4.17	8.20	8.77	
Excavate & Haul from Site	0.69 CY	5.93	4.09	11.28	7.65	
Backfill & Compact	1.07 CY	11.71	12.53	3.15	3.37	
Respread Topsoil	0.19 CY	1.50	0.29	1.00	0.19	
Seed	1.19 CY	0.30	0.36	0.35	0.42	42.56
Screeds	3.00 SF	0.06	0.18	0.08	0.24	
Edge Form	2.00 LF	1.36	2.72	0.42	0.84	
Wall Forms	16.00 SF	2.56	40.96	0.87	13.92	
Key	2.00 LF	0.41	0.82	0.13	0.26	
Set Embedded Plates	0.20 EA	6.00	1.20	5.25	1.05	
Fine Grade	5.00 SF	0.06	0.30	0.00	0.00	
Pour Slab on Grade	0.09 CY	16.00	1.44	54.00	4.86	
Pour Walls	0.30 CY	27.40	8.22	54.00	16.20	
Rebar	60.00 LB	0.14	8.40	0.25	15.00	
Trowel Finish	3.00 SF	0.41	1.23	0.00	0.00	
Misc. Sump Pits						
Construct Joints, etc.	LS		5.24		4.19	
Precast Slab Cover - 6"	3.50	0.80	2.80	4.80	16.80	
Steel Channel	1.50	0.20	0.30	0.63	.95	
Gasket	2 LF	0.34	0.68	0.50	1.00	
Touch-up Welds	0.20 EA	1.20	0.24	0.15	0.03	150.07
Subtotal - Cost			96.63		96.00	192.63
Subcontractor Overhead & Profit @ 20%			19.33		19.20	38.53
Subtotal			115.96		115.20	231.16
Prime Contractor's Overhead & Profit @ 5%			5.80		5.76	11.56
Total (\$1F)			121.76		120.96	242.72



Following the same estimating procedure, the following costs (including overhead & profit) are obtained:

<u>STEAM</u>		<u>TRENCH</u>	<u>PIPING</u>
1" Steam Supply - 1" Condensate Return		\$213.59	\$ 60.99
1-1/2" Steam Supply - 1" Condensate Return		213.59	62.24
2" Steam Supply - 1" Condensate Return		213.59	62.26
3" Steam Supply - 1-1/2" Condensate Return		213.59	82.66
4" Steam Supply - 2" Condensate Return		216.83	88.26
6" Steam Supply - 3" Condensate Return		84 1/2% 226.54	34 1/2% 123.65
8" Steam Supply - 4" Condensate Return		10 1/2% 229.77	19 1/2% 136.62
10" Steam Supply - 6" Condensate Return		13 1/2% 239.48	17 1/2% 177.09
12" Steam Supply - 6" Condensate Return		242.42	190.99

92.37  
114.94  
176.01

#### HIGH TEMPERATURE HOT WATER

1" Supply/ Return	213.59	60.37
1-1/2" Supply/Return	213.59	63.79
2" Supply/Return	213.59	63.78
3" Supply/Return	218.45	97.48
4" Supply Return	221.68	107.36
6" Supply Return	233.01	144.55
8" Supply Return	239.48	156.96
10" Supply/Return	245.95	197.60
12" Supply/Return	252.43	224.20

Note that all costs are in \$LF

# ANALYSIS OF VARIOUS SIZED SHALLOW TRENCH HEAT DISTRIBUTION SYSTEMS

## CONCRETE SHALLOW TRENCH - STEAM DISTRIBUTION SYSTEM

DESCRIPTION	QUANTITY UNIT	TOTAL LABOR (\$)	TOTAL MATERIAL & EQUIPMENT	GROUP TOTAL
<u>PIPING</u>				
Schedule 40 Supply & Supports - 12"	1 LF	36.11	18.20	
Schedule 80 Return & Supports - 6"	1 LF	22.54	10.26	
Insulation & Jacket Supply - 3"	1 LF	7.10	10.62	
Insulation & Jacket Return - 3"	1 LF	7.10	6.80	
Anchors	1 LF	1.25	1.33	
Valve Vault (1/300')	1 LF	3.87	16.67	
Expansion Loop	1 LF	7.57	2.96	
Sutotal		85.54	66.84	
Mechanical Overhead & Profit @ 25%		21.39	16.71	
Total Piping (per LF)		106.93	83.56	190.49
Concrete Trench	1 LF	121.76	120.96	242.72
TOTAL (\$/SF)		228.69	204.52	433.21

PRESENT WORTH LIFE CYCLE COSTING FOR DIRECT BURIED CONDUIT HEAT DISTRIBUTION SYSTEMS

DISCOUNT RATE = 10%      INFLATION RATE = 0%      STEAM      PIPE SIZE= 8.0

C O S T S

YEAR	CONCEPTS PLANNING	DESIGN	CONSTR.	MAINT. REPAIR	OPER.	TOTAL	DISCOUNT FACTOR	DISCOUNTED ANNUAL COST	ACCUMULATIVE DISCOUNTED COST
0	21,948					21,948	1.000	21,948	21,948
1		87,792				87,792	0.954	83,753	105,701
2			1,463,193			1,463,193	0.867	1,268,588	1,374,289
3				9,000	62,209	71,209	0.788	56,113	1,430,402
4				9,000	65,568	74,568	0.717	53,465	1,483,868
5				9,000	69,109	78,109	0.652	50,927	1,534,795
6				9,000	73,947	82,947	0.592	49,104	1,583,899
7				9,000	79,123	88,123	0.538	47,410	1,631,309
8				9,000	84,661	93,661	0.489	45,800	1,677,110
9				9,000	90,588	99,588	0.455	45,312	1,722,422
10				9,440	96,929	106,369	0.405	43,079	1,765,501
11				9,923	100,612	110,535	0.368	40,677	1,806,178
12				10,494	104,435	114,929	0.334	38,386	1,844,565
13				10,846	108,404	119,250	0.304	36,252	1,880,817
14				11,198	112,523	123,721	0.276	34,147	1,914,964
15				11,593	116,799	128,392	0.251	32,226	1,947,190
16				11,945	122,055	134,000	0.228	30,552	1,977,742
17				12,340	127,548	139,888	0.208	29,097	2,006,839
18				12,648	133,287	145,935	0.189	27,582	2,034,421
19				12,868	139,285	152,153	0.172	26,170	2,060,591
20				13,175	145,553	158,728	0.156	24,762	2,085,353
21				13,395	149,920	163,315	0.142	23,191	2,108,543
22				13,659	154,417	168,076	0.129	21,682	2,130,225
23				13,835	159,050	172,885	0.117	20,228	2,150,453
24				14,054	163,821	177,875	0.107	19,033	2,169,486
25				14,274	168,736	183,010	0.097	17,752	2,187,237

PRESENT WORTH LIFE CYCLE COSTING FOR CONCRETE SHALLOW TRENCH HEAT DISTRIBUTION SYSTEM IDEAL CASE

DISCOUNT RATE = 10%

INFLATION RATE = 0%

STEAM

PIPE SIZE =

8.000

C O S T S

YEAR	CONCEPTS		MAINT.		TOTAL	DISCOUNT FACTOR	DISCOUNTED ANNUAL COST	ACCUMULATIVE DISCOUNTED COST
	PLANNING	DESIGN	CONSTR.	REPAIR	OPER.			
0	29,018					1.000	29,018	29,018
1		116,072				0.954	110,733	139,751
2			1,934,539			0.867	1,677,245	1,816,996
3				1,000	68,453	0.788	54,729	1,871,725
4				1,000	72,149	0.717	52,448	1,924,174
5				1,000	76,046	0.652	50,234	1,974,407
6				1,000	81,369	0.592	48,762	2,023,170
7				1,000	87,065	0.538	47,379	2,070,548
8				1,000	93,159	0.489	46,044	2,116,592
9				1,000	99,680	0.455	45,809	2,162,401
10				1,000	106,658	0.405	43,601	2,206,003
11				1,000	110,711	0.368	41,110	2,247,112
12				1,000	114,918	0.334	38,717	2,285,829
13				1,000	119,285	0.304	36,567	2,322,396
14				1,030	123,817	0.276	34,458	2,356,853
15				1,059	128,523	0.251	32,525	2,389,378
16				1,074	134,306	0.228	30,867	2,420,245
17				1,103	140,350	0.208	29,422	2,449,667
18				1,103	146,666	0.189	27,928	2,477,596
19				1,118	153,266	0.172	26,554	2,504,150
20				1,118	160,162	0.156	25,160	2,529,309
21				1,133	164,967	0.142	23,586	2,552,896
22				1,143	169,916	0.129	22,067	2,574,963
23				1,148	175,014	0.117	20,611	2,595,574
24				1,162	180,264	0.107	19,413	2,614,986
25				1,177	185,672	0.097	18,124	2,633,111

APPENDIX H

PAVEMENT DATA

(SOURCE: JASPERS AND SINHA 1990)



**US Army Corps  
of Engineers**  
Construction Engineering  
Research Laboratory

USACERL Unpublished Technical Report M-91/03

October 1990

Automated Pavement Evaluation/Dynamic Modeling of  
Pavement Performance/Maintenance Costs

## **A Study of Rigid Pavement Maintenance and Repair Costs at Three Army Installations**

by  
Martin W. Jaspers  
Kumares C. Sinha

Much of the pavement infrastructure on military installations in the United States was constructed more than a decade ago. Unfortunately, the system is now rapidly deteriorating. Engineers at Army installations need an understanding of the costs necessary to maintain pavements at given conditions in order to estimate budget needs. To help installation managers and engineers, USACERL developed a pavement management system known as PAVER. However, engineers do not have accurate unit maintenance and repair costs that can be used with PAVER.

The objective of this research was to determine unit maintenance, repair, and reconstruction costs for Portland cement concrete (PCC) roadway and airfield apron pavements. Existing PAVER data bases from Fort Ord, CA; Fort Rucker, AL; and Fort Eustis, VA were used for analysis. This report contains the unit maintenance, repair, and reconstruction costs for PCC pavements at those three installations.

Similar analyses should be conducted with data from other installations, for comparison and to facilitate development of regional default cost values. Available PCC data should be augmented with information from all available sources, and that information on pavement overlays and pavement recycling be included in the analysis when it becomes available.

Unpublished report.

## 5 ESTIMATION OF EQUIVALENT UNIFORM ANNUAL COST

A life cycle cost analysis based on the EUAC must be performed so that a comparison of the unit costs of maintenance, repair, and reconstruction activities can be made. The EUAC method enables the user to compare alternatives that do not necessarily have the same service life or pattern of annually occurring costs. In this method, all initial investment costs and all annually occurring costs are converted to present worth and are then transformed into an equivalent annual cost sum over the project's economic service life.

### The Analysis Procedure

The EUAC life cycle cost analysis procedure is composed of the following sequential steps:

1. Determine the total initial cost of the maintenance, repair, or reconstruction activity. For the installations studied, the total initial costs by PCI range are given in Appendix D.

2. Determine the economic service life of the repair or reconstruction activity. For the installations studied, the economic service life can be found in the tables in Appendix C or by using one of the following equations:

a. Pavement surface thickness in inches

$$\text{Service Life} = \left| \frac{30 * 25.4 (\text{Surface Thickness})^d}{b} \right|^{0.909} \quad [\text{Eq 7}]$$

b. Pavement surface thickness in mm

$$\text{Service Life} = \left| \frac{30 * (\text{Surface Thickness})^d}{b} \right|^{0.909} \quad [\text{Eq 8}]$$

The values of b and d are found in Appendix C.

3. Determine the EUAC of the initial (EUAC<sub>i</sub>) cost of repair or reconstruction using the following equation:

$$\text{EUAC}_i = \text{IC} * (\text{CRF}_{i,n}) \quad [\text{Eq 9}]$$

where IC = initial cost determined under Step 1

$$\text{CRF} = \text{Capital Recovery Factor} = \frac{i(1+i)^n}{(1+i)^n - 1}$$

i = discount rate (6 percent)

n = economic service life of the pavement as determined under Step 2.

4. Determine the EUAC of maintenance ( $\text{EUAC}_m$ ) after repair or reconstruction throughout the economic service life by the following steps:

a. Estimate the period length during which the pavement section's condition is within each of the following ranges:

Range Number	1	100 - 90 PCI
	2	89 - 80 PCI
	3	79 - 70 PCI.

This can be done by using the following equations:

i. Pavement surface thickness in inches:

$$\text{Period Length} = \left| \frac{DF * 25.4 (\text{Surface Thickness})^d}{b} \right|^{0.909} \quad [\text{Eq 10}]$$

ii. Pavement surface thickness in mm:

$$\text{Period Length} = \left| \frac{DF * (\text{Surface Thickness})^d}{b} \right|^{0.909} \quad [\text{Eq 11}]$$

where Period Length = length of the period in Range 1, 2, or 3

DF = 100 - (lower limit PCI range, 10 for Range 1, 20 for Range 2, 30 for Range 3)

b = coefficient from the appropriate table in Appendix C

d = exponent value from the appropriate table in Appendix C.

b. Estimate the average maintenance expenditure for each of the ranges mentioned in Step 4a. This information can be extracted from Appendix D.

c. Discount all future maintenance costs to the present worth and multiply the amount by the capital recovery factor (CRF) to determine the equivalent uniform annual cost. This can be done by using the following equation:



$$EUAC_m = [C1(USPWF, i, n1) + C2(USPWF, i, n2) * (SPPWF, i, n1) + C3(USPWF, i, n3) * (SPPWF, i, (n1 + n2))] * [CRF, i, (n1 + n2 + n3)] \quad [Eq 12]$$

where

- c1 = cost in period 1
- c2 = cost in period 2
- c3 = cost in period 3
- n = number of years
- n1 = period length in Range 1 (100 - 90)
- n2 = period length in Range 2 (89 - 80)
- n3 = period length in Range 3 (79 - 70)
- i = discount rate

$$USPWF = \text{uniform series present worth factor} = \frac{(1+i)^n - 1}{i(1+i)^n}$$

$$SPPWF = \text{single payment present worth factor} = \frac{1}{(1+i)^n}$$

$$CRF = \text{capital recovery factor} = \frac{i(1+i)^n}{(1+i)^n - 1}$$

5. Determine the total EUAC for the economic service life of each alternative by adding the values from Steps 3 and 4.

$$EUAC = EUAC_i + EUAC_m$$

The life cycle cost analysis output provides the user with unit cost information. Information on AC or PCC overlays over PCC pavements should be included in the analysis as data becomes available. The analysis procedure will not change substantially for these alternatives.

The described life cycle costing procedure was repeated for all pavement classes and for each of the PCI ranges for each of the installations included in this study. The results are included in Appendix D.

#### *Numerical Example*

The calculation of the EUAC for the repair of an 8-in. PCC roadway pavement with a PCI value between 100 and 81 at Fort Eustis is illustrated here.

Step 1. The total unit initial cost for the repair activity (from Appendix D) is \$4.55/sq yd.

Step 2. The economic service life of the repaired pavement section (using Equation 7 or Appendix C) is 30 years.

Step 3. The  $EUAC_i$  of the initial cost of the activity (using Equation 9 or Appendix D) is \$0.32/sq yd.

Step 4. The periods during which the pavement section's condition is within Ranges 1, 2, and 3 are obtained by using Equation 10. The period in Range 1 is 11 years; in Range 2 is 11 years, and in Range 3 is 10 years. Average maintenance costs during a given period after repair is estimated for each of the ranges. These values can be found in Appendix D. For this example, the values are \$0.38/sq yd in period 1, \$0.65/sq yd in period 2, and \$0.93/sq yd in period 3. These average maintenance costs are then brought back to present worth by multiplying with the appropriate compound interest factors. The total sum is then multiplied by the CRF to estimate the  $EUAC_m$  for maintenance over the economic service life of the pavement. For this example, the value of  $EUAC_m$  is equal to the sum of  $EUAC$  in period 1 = \$0.21/sq yd; period 2 = \$0.19/sq yd; and period 3 = \$0.12/sq yd.  $EUAC_m = \$0.21 + \$0.19 + \$0.12 = \$0.52/\text{sq yd}$ .

Step 5. The total  $EUAC$  of the repair activity of the roadway is determined.  $\text{Total } EUAC = EUAC_i + EUAC_m$ .

The life cycle costing procedure detailed in this chapter was applied to Forts Rucker, Eustis, and Ord. Results of the analysis procedure are given in Appendix D. Figures D9 to D17 show the total  $EUAC$  at each installation for each branch use and pavement thickness.

### Sensitivity Analysis

Results of an economic analysis are only as good as the estimates of the parameters, economic service life, initial cost, maintenance cost, and the discount rate. A sensitivity analysis was performed to measure the effects of changes in parameter values of the equivalent uniform annual life cycle costs. The results of the sensitivity analysis are listed in Appendixes E and F. Examples are shown in Tables 10 and 11.

### Pavement Service Life

The actual economic service life may vary from the predicted service life. To determine the effect of a different economic service life on the  $EUAC$ , the estimated pavement service life was varied by plus and minus ( $\pm$ ) 25 percent. The  $EUAC$  was then calculated for these two conditions. The results of this analysis are given in Appendix F. Varying the economic service life of a repaired pavement by  $\pm$  25 percent, the equivalent uniform annual costs changed by between -3 and +9 percent for 8-in. pavements, between -6 and +11 percent for 6-in. pavements, and from -3 to +9 percent for 7-in. pavements. Therefore, it may be assumed that an error in the prediction of the pavement service life may result in a relatively small error in the  $EUAC$  of PCC pavement sections of 7 or 8 in. thick. A slightly larger error may be expected for 6-in. pavements. Adjusting a reconstructed pavement section's economic service life by  $\pm$  25 percent, the  $EUAC$  changed by between -6 to +12 percent for 8-in. pavements, from -7 to +14 percent for 7-in. pavements, and between -8 to +14 percent for 6-in. pavements. A variation in a pavement section's service life leads to a greater variance for new sections than for repaired sections.

### Discount Rate

High discount rates favor alternatives with a low initial cost and high annually occurring maintenance costs. In the case of low discount rates, alternatives with high initial costs and low

maintenance costs are favored. The initial analysis was based on a discount rate of 6 percent. The sensitivity analysis was performed with discount rates of 4, 5, 6, 7, and 8 percent. The results are listed in Appendix F. An example may be found in Table 10. The impact of changing discount rates on the EUAC of maintenance and repair activities was substantial. It resulted in fluctuations within a range of -12 to +12 percent in the EUAC. The EUAC for reconstructed sections usually varied between -17 and +18 percent around the base discount rate of 6 percent. It should be noted that the discount rates used here are simply for illustration; they do not represent the Army policy.

#### *Initial Costs*

By varying the initial cost of maintenance and repair activities by  $\pm 25$  percent, the EUAC values were found to vary between +17 percent and -14 percent, respectively. The variation of the initial cost of reconstruction by  $\pm 25$  percent led to large fluctuations in the calculated EUAC. For all pavement thicknesses and at each of the three installations, the EUAC varied between  $\pm 22$  percent.

#### *Maintenance Costs*

The variation of the annually occurring maintenance costs by  $\pm 25$  percent caused the EUAC to vary within a range of  $\pm 10$  percent.

#### *Implications of the Sensitivity Analysis*

A conclusion of the analysis is that the calculated EUAC of each of the alternatives is most sensitive to pavement economic service life. Other factors, such as discount rate, initial cost, and maintenance cost, are also important in estimating the total EUAC of an activity (see Table 11).